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CORNELL AERONAUTICAL LABORATORY, INC.

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APPROXIMATE SOLUTIONS FOR NONEQUILIBRIUM AIRFLOW IN HYPERSONIC NOZZLES

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FOREWORD

This technical note was prepared as part of the Wave Superheater Hypersonic Tunnel project being constructed at Cornell Aeronautical Laboratory, Inc., Buffalo, New York.

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ABSTRACT

A method has been described to estimate the effects of finite chemical reaction rates on the one-dimensional expansion of air in hypersonic nozzles. The calculations have considered stagnation temperatures from 4000 to 6000°K, stagnation pressures from 100 to 1000 atmospheres, and a range of wedge and axisymmetric nozzle shapes. Vibrational equilibrium is assumed.

A relaxation length criterion has been applied to a simplified kinetic model of air to determine the approximate location of freezing for flow with finite reaction rates in each nozzle configuration. Equilibrium composition profiles obtained by machine calculation were used for the calculation of the relaxation lengths. The resultant chemically frozen expansions have been calculated and are presented in tabular and graphical form. In all cases freezing occurs fairly early in the nozzle. Further, freezing in the nozzle is delayed by an increase in stagnation pressure, an increase in stagnation temperature, and by the use of gradually expanding nozzles. The effect of freezing is to reduce the pressure, velocity and temperature at a particular area ratio from the corresponding equilibrium values, and to increase the density and Mach number. The change in temperature and Mach number may be considerable whereas the density and flow velocity are relatively unaffected by freezing.

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NOTATION

Dimensional

A'	cross sectional area of nozzle
D	dissociation energy per mole
ΔF_ℓ°	change in standard free energy for ℓth reaction
h_i'	enthalpy of ith species including energy of formation, cal/mole
h	Planck's constant
H'	enthalpy of mixture, cal/gm
k_f	dissociation rate coefficient, cm^3/mole sec
k_R	recombination rate coefficient, cm^6/mole^2 sec
K_e	equilibrium constant = k_f / k_R , mole/cm^3
$K_{p\ell}, K_{x\ell}$	equilibrium constant referred to partial pressures and mole fractions respectively
K	Boltzmann constant
ℓ	characteristic nozzle dimension L/a
L	characteristic throat dimension, cm
m'	mass flow $\rho' u' A'$
p'	fluid pressure
r'	local relaxation length, Equation (35)
r'_∞	local relaxation length based on infinite-rate equilibrium, Equation (36)
R_0	universal gas constant
S_0'	entropy (per unit mass) at reservoir conditions
$S_i^{\circ\prime}$	molar entropy of ith species at standard pressure
T'	local absolute temperature of gas

u' local gas velocity

x' distance from nozzle throat

γ_i concentration of species i, moles/gm

θ'_D characteristic dissociation temperature D/R_o

θ'_V characteristic vibrational temperature $h\nu/K$

μ molecular weight of undissociated mixture

$\bar{\mu}$ molecular weight of mixture

ν characteristic frequency of molecule

ρ' fluid density

ψ parameter $\dfrac{2\ell\rho_o'^2}{\sqrt{\frac{R_o T_o'}{\mu}}} k_{R_o}^{(2)}$

<u>Dimensionless</u>

a tangent of nozzle semi-angle

A_{jk} member of correction coefficient matrix in Newton-Raphson method

A A'/A'_*

c number of linearly independent species

F_j function used in Newton-Raphson method defined by Equations (A-2) and (A-3)

h_i $h'_i/R_o T_o'$

h_k fractional correction to the kth independent variable in Newton-Raphson iteration

H $H'/\frac{R_o T_o'}{\mu}$

m mass flow $\rho u A$

m number of chemical elements present

M Mach number

M_i chemical formula of ith species

n exponent in area relation $A = 1 + x^n$

p p'/p_o'

q_j mole fraction of j th component in a hypothetical system containing components only

Q_k number of gram atoms of kth chemical element present

r r'/ℓ

r_∞ r_∞'/ℓ

s number of species

s_o s_o'/R_o

S_i° $S_i^{\circ\prime}/R_o$

T T'/T_o'

u $u'/\sqrt{\frac{R_o T_o'}{\mu}}$

x x'/ℓ

X_i mole fraction of i th species

y_i formula vector of i th species

α_{jk} atoms of kth chemical element per molecule of j th chemical species

β_i $k_f^{(i)}/k_f^{(2)}$, Equation (32)

δ_{jk} Kronecker delta

ϵ_h maximum permissible fractional correction to mole fractions

θ_D θ_D'/T_o'

θ_V θ_V'/T_o'

$\nu_{\ell j}$ stoichiometric coefficients

ρ ρ'/ρ_0'

Subscripts

α, i, j, k, ℓ sum, product or matrix indices

o denotes condition at reservoir

e denotes local equilibrium value

∞ denotes infinite-rate equilibrium value

$*$ denotes value at throat, A = 1

f denotes value at freezing

I INTRODUCTION

The stagnation enthalpies encountered in the flow of gases through nozzles at low supersonic velocities are usually sufficiently low so that chemical kinetics are unimportant. Such flows may be accurately described by simple equations which consider the participitation of only the translational and rotational degrees of freedom of the molecules (constant γ). However, in the high temperature flows occurring in hypersonic nozzles, such simplified considerations are no longer applicable because of the interchange of energy between the internal and translational degrees of freedom and the coupling of the chemistry with the gas dynamics through dissociation. Figure 1 shows that at stagnation conditions pertinent to the present study, a significant portion of the total energy resides in the internal energy modes.

The gas dynamic and chemical behavior of a high temperature gas undergoing expansion in complete equilibrium may be calculated with reasonable precision (Sec. II). Complete chemical equilibrium, however, implying infinite reaction rates, is a condition which may only be approached, to a greater or lesser degree, in the expansion of high temperature real gases. Studies of the effects of chemical nonequilibrium, in particular nozzle flows[1, 2, 3, 4] involving only a single dissociating molecular species, have shown that the flow properties may depart considerably from their local equilibrium values. The effect of finite chemical reaction rates, as well as nozzle geometry, may result in actual freezing of the gas composition as some point in the nozzle.

The purpose of this report is to present quantitative estimates for the effect of flow freezing on the departure of test section properties from their equilibrium values in the expansion of air through hypersonic wind tunnel nozzles. The analysis has considered stagnation temperatures from 4000°K to 6000°K and stagnation pressures from 100 to 1000 atmospheres, representing a range of stagnation enthalpies of either current or future interest. The expansions are considered for two nozzle configurations; a two-dimensional wedge-type nozzle with a sharp throat and a hyperbolic axisymmetric nozzle

which is conical for large area ratios. The solutions cover a comprehensive range of geometries for both types of nozzle.

The outline of the report is as follows. The equilibrium chemical composition of the gas at the reservoir condition is first computed for all stagnation states by the method outlined in Sec. II. The equilibrium (infinite-rate) expansions are then calculated, the solutions providing both the gas dynamic behavior and gas composition as a function of temperature. Because of their usefulness, the results of the equilibrium calculations are included in this report in tabular and graphical form.

The concept of a local chemical relaxation length[5] is then introduced (Sec. III) and used to develop an approximate criterion for freezing. This concept was first used to develop a freezing criterion in Ref. 3, for both a pure diatomic gas or diatomic gas plus any diluent. Some air calculations were also performed in Ref. 3. The present kinetic model for air assumes finite reaction rates for oxygen, with nitrogen and nitric oxide assumed to remain in chemical (infinite-rate) equilibrium. A relaxation length is calculated, based upon the equilibrium flow properties, and used to determine the approximate nozzle location at which appreciable freezing has occurred, i.e., to predict, approximately, the final chemical state of the expanding flow for finite reaction rates.

Finally (Sec. IV), calculation of the nozzle expansions are completed with all chemical species fixed at their "freezing" mass fractions. The equilibrium solutions serve as a basis of comparison for the frozen (zero-rate) solutions. Both the equilibrium and frozen expansion processes are isentropic.[14] The comparisons have been referred to as providing quantitative "estimates" since although the calculations of the frozen expansions are in themselves exact, the criterion for the selection of the equilibrium state to serve as input to the frozen calculations is approximate.

II SOLUTION OF THE EQUILIBRIUM FLOW

A. Governing Equations

It is assumed that the gas is a mixture of ideal gases, that the flow is quasi-one-dimensional, and that diffusion, heat conduction and viscous processes are of negligible significance. Steady, adiabatic, critical flow is assumed to exist in the nozzle.

The equations which determine the flow are,

Conservation of Momentum:

$$u' \, du' + \frac{dp'}{\rho'} = 0 \tag{1}$$

where u' = velocity
p' = pressure
ρ' = density

Global Conservation of Energy:

$$\frac{u'^2}{2} + H' = H_0' \tag{2}$$

where H' = mixture enthalpy (cal/gm)

Global Conservation of Mass:

$$m' = \rho' u' A' \tag{3}$$

where m' = mass flow
A' = cross-sectional area

The state equations are,

Thermodynamic State:

$$p' = \rho' \frac{R_o}{\bar{\mu}} T' \tag{4}$$

where $\bar{\mu}$ = molecular weight of mixture and is given by

$$\bar{\mu} = \frac{1}{\sum_{i=1}^{S} \gamma_i} \tag{5}$$

where γ_i = mass concentration of species i in moles per unit mass.

Caloric State:

$$H' = \sum_{i=1}^{S} \gamma_i h_i' \tag{6}$$

where h_i' = molar enthalpy of ith species including thermal and formation contributions. h_i' is only a function of temperature.

In dimensionless form, the equations are written

$$u\,du + \frac{dp}{\rho} = 0 \tag{7}$$

$$\frac{u^2}{2} + H = H_o \tag{8}$$

$$m = \rho u A \tag{9}$$

$$p = \rho T \frac{\sum_{i=1}^{S} \gamma_i}{\sum_{i=1}^{S} \gamma_{i_o}} \tag{10}$$

$$H = \mu \sum_{i=1}^{s} \gamma_i h_i \qquad (11)$$

where

$$u = u' \Big/ \sqrt{\frac{R_o T_o'}{\mu}}$$

$$H = H' \Big/ \frac{R_o T_o'}{\mu}$$

$$p = p'/p_o'$$

$$\rho = \rho'/\rho_o'$$

$$T = T'/T_o'$$

$$A = A'/A_*'$$

μ = molecular weight of undissociated (cold) gas

R_o = Universal gas constant

A_*' = throat area

Except for the molecular weight, μ , the reference conditions for the non-dimensional forms are those at the equilibrium reservoir state.

B. Equilibrium Analysis

The methods and notation of Brinkley[6] were used for the equilibrium analysis wherever applicable. At the end of this section, the Brinkley technique is extended to include the computation of states along an isentropic path.

The chemical formula of the ith species may be expressed in vectorial form as

$$y_i = (\alpha_{i1}, \alpha_{i2}, \cdots \alpha_{ik}, \cdots \alpha_{im}) \qquad (i = 1, 2, \cdots s) \tag{12}$$

where α_{ik} is the number of atoms of the kth chemical element per molecule of the i th species and m is the number of elements present. If the rank of the matrix of α_{ik} is c, there exist c linearly independent y_i, and $(s-c)$ dependent y_i which are given by linear combinations of the c independent ones.

$$\sum_{j=1}^{c} \nu_{\ell j} \, y_j = y_\ell \quad (\ell = c+1, \ c+2, \cdots s) \tag{13}$$

As expressed by Eq. (13), $\nu_{\ell j}$ are coefficients in the linear dependencies of vectors y_ℓ upon y_j.

In the equilibrium analysis the independent species are designated (j = 1, 2 ..... c) and are called "components." The number of components c usually equals the number of chemical elements present m. Equations (13) correspond to $(s-c)$ chemical reactions postulated to form the dependent species if the formula vectors are replaced with chemical symbols.

It is useful to consider a hypothetical system. This system has the same atomic constitution as the actual system, but is chemically combined such that only components are present. If Q_k is the number of gram-atoms of the kth element present, and q_j' is the number of moles of the j th component contained in the hypothetical system, then

$$\sum_{j=1}^{c} \alpha_{jk} \, q_j' = Q_k \qquad (k = 1, 2, \cdots m) \tag{14}$$

The q_j' are normalized by

$$q_j = \frac{q_j'}{\sum_{j=1}^{c} q_j'} \tag{15}$$

thereby scaling the total size of the system if q_j are considered to be numbers of moles.

Global mass conservation may be expressed by

$$\sum_{j=1}^{c} n_j \mu_j + \sum_{\ell=c+1}^{s} n_\ell \mu_\ell = \sum_{j=1}^{c} q_j \mu_j \tag{16}$$

where μ_j is the molecular weight and n_j is the number of moles of j th species. Mass is conserved in each formation reaction of Eqs. (13) so that

$$\mu_\ell = \sum_{j=1}^{c} \nu_{\ell j} \mu_j \quad (\ell = c+1,\ c+2,\ \cdots s) \tag{17}$$

Substituting μ_ℓ from Eq. (17) and equating coefficients of μ_j in Eq. (16) gives

$$n_j + \sum_{\ell=c+1}^{s} \nu_{\ell j} n_\ell = q_j \qquad (j = 1,\ 2,\ \cdots c) \tag{18}$$

Division of Eq. (18) by the total number of moles n gives

$$X_j + \sum_{\ell=c+1}^{s} \nu_{\ell j} X_\ell = \frac{q_j}{n} \qquad (j = 1,\ 2,\ \cdots c) \tag{19}$$

where X are mole fractions. By definition

$$\sum_{j=1}^{c} X_j + \sum_{\ell=c+1}^{s} X_\ell = 1 \tag{20}$$

Equation (19) is summed over j to give

$$\sum_{j=1}^{c} X_j + \sum_{\ell=c+1}^{s} \nu_\ell X_\ell = \frac{1}{n} \tag{21}$$

where

$$\nu_\ell = \sum_{j=1}^{c} \nu_{\ell j}$$

Substituting for X_j from Eq. (20) into Eq. (21) results in

$$1 + \sum_{\ell=c+1}^{s} (\nu_\ell - 1) X_\ell = \frac{1}{n} \tag{22}$$

Therefore, Eq. (19) may be written

$$X_j = q_j - \sum_{\ell=c+1}^{s} \left[\nu_{\ell j} - q_j (\nu_\ell - 1) \right] X_\ell \qquad (j = 1, 2, \cdots c) \tag{23}$$

giving c of the s equations necessary for determining the equilibrium composition at a specified temperature and pressure. The remaining equations are

$$X_\ell = K_{x\ell} \prod_{j=1}^{c} X_j^{\nu_{\ell j}} \qquad (\ell = c+1, c+2, \cdots s) \tag{24}$$

where $K_{x\ell}$ are equilibrium constants based on mole fractions. These constants are related to $K_{p\ell}$ by

$$K_{x\ell} = K_{p\ell} \, p'^{(\nu_\ell - 1)} \qquad (\ell = c+1, c+2, \cdots s) \tag{25}$$

$K_{p\ell}$ are calculated from chemical potentials by

$$K_{p\ell} = \exp \left(- \frac{\Delta F_\ell^\circ}{R_o T'} \right) \tag{26}$$

where ΔF_ℓ° is the change in free energy at standard pressure for the ℓ th reaction. The ΔF_ℓ° were calculated by means of polynomial fits to various tabulated and derived thermodynamic functions provided by R. E. Duff of Los Alamos Scientific Laboratory. Equations (23) and (24) determine the equilibrium composition when temperature and pressure are specified; therefore, they can be employed for the reservoir state calculations.

For computation along an isentropic path, the Brinkley method must be modified. The composition and pressure will be computed at various temperatures for the entropy at the prescribed reservoir state. Since pressure

is an additional unknown quantity, one more equation is required. A statement that entropy is a constant is the desired equation.

$$s_0 = \frac{1}{\bar{\mu}} \sum_{i=1}^{s} X_i S_i^\circ - \sum_{i=1}^{s} X_i \ln X_i - \ln p' \qquad (27)$$

s_0 is the entropy (per unit mass) calculated at the reservoir state, and $\bar{\mu}$ is the mixture molecular weight which is calculated from

$$\bar{\mu} = \sum_{i=1}^{s} X_i \mu_i$$

S_i° is the molar entropy of the i th species at standard pressure. Simultaneous solution of the nonlinear algebraic equations (23), (24), and (27) gives the composition and pressure at various temperatures along an isentrope characterized by s_0. The Newton-Raphson method as employed in the solution is outlined in Appendix A.

Additional quantities are computed from the results of the solution. Concentrations in moles per unit mass γ_i are found from

$$\gamma_i = \frac{X_i}{\bar{\mu}} \qquad (i = 1, 2, \cdots s) \qquad (28)$$

Density is found from Eq. (4), enthalpy from Eq. (6), velocity from Eq. (2), and mass flow per unit area m'/A' from Eq. (3). The state at which mass flow per unit area goes through a maximum defines the conditions at the throat of the equilibrium nozzle. The local to throat area ratios are then found by dividing the maximum m'/A' by the local m'/A' values. A Mach number is calculated at each step from the expression

$$M = u \Big/ \sqrt{\left(\frac{dp}{d\rho}\right)_{\substack{\text{isentropic}\\ \text{equilibrium}}}} \qquad (29)$$

The thermodynamic state is independent of the form of $A(x)$ because the satisfaction of equilibrium conditions at any area is independent of the history of the flow.

The equilibrium air expansions were calculated on the CAL IBM-704 computer* for reservoir temperatures of 4000, 5000, 6000, 7000, and 8000°K and reservoir pressures of 100, 300, and 1000 atmospheres. The calculations assumed a 13 chemical specie system for air. The solutions for the gas dynamic properties and gas composition are presented for each equilibrium expansion in Tables 1-16. In addition, the air composition is shown as a function of area ratio for each case in Figs. 2-17.

*The Fortran programming for IBM machine computation was done by D. B. Larson, Computer Applications Branch, Systems Research Department, Cornell Aeronautical Laboratory. The IBM-704 program used in the solution of the equilibrium flow is availabla at CAL. In the event further equilibrium flow calculations are required, details will be provided upon request.

III APPROXIMATE SOLUTIONS FOR FINITE-RATE AIR EXPANSIONS

A. Relaxation Length Criterion for Freezing

The solution of nonequilibrium flows, which involve finite reaction rates, is rendered difficult by the need for simultaneous solution of interrelated chemical rate equations and the gas dynamic equations. Also, at the present time, the magnitudes of the required rate constants, and their temperature dependence, are still not known with certainty. It is worthwhile, therefore, to investigate a simple method for the approximate calculation of the final state of a gas undergoing expansion with finite reaction rates.

The present approach is that of Ref. 3 in which specific non-equilibrium airflows in hypersonic nozzles were calculated on the basis of a relaxation length. The results of the previous studies[2,3] have shown that for flows involving a single relaxing species, the use of a local relaxation length, evaluated for the corresponding equilibrium flow, provides an excellent estimate of the final frozen state of the gas obtained from exact finite-rate solutions. Accordingly, a relaxation length is introduced in the air calculations on the basis of an assumption concerning the relative importance of the various chemical reactions.

The energy associated with the normally inert degrees of freedom for the air species, as a fraction of the total enthalpy, is shown in Fig. 1. It is seen that over the range of reservoir conditions pertinent to the present frozen expansion calculations, i.e., from 4000 to 6000°K, oxygen dissociation is the most important internal mode as it represents the source of greatest energy loss due to freezing. The percentage of the gas enthalpy associated with nitrogen dissociation is small compared with that of oxygen. Furthermore, since the energy associated with the formation of nitric oxide is small and essentially constant over a wide range of temperatures and pressures, the potential energy loss due to freezing of the nitric oxide composition is also quite small. Consequently, a relaxation length is derived assuming that only oxygen dissociation-recombination reactions occur at finite rates.

The reaction may be written

$$O + O + M_i \underset{k_R^{(i)}}{\overset{k_f^{(i)}}{\rightleftarrows}} O_2 + M_i$$

where M_1 = oxygen atom

M_2 = oxygen molecule

M_3 = nitrogen atom

M_4 = nitrogen molecule

M_5 = nitric oxide molecule

The equilibrium constant in terms of molar concentrations per unit mass (γ_i) has the assumed form

$$K_e(T') = \frac{k_f^{(i)}}{k_R^{(i)}} = \rho' \frac{\gamma_{o_e}^2}{\gamma_{o_{2e}}} \tag{30}$$

where $k^{(i)}$ are reaction rate coefficients. The subscript e denotes the local equilibrium value. The rate equation is then

$$\begin{aligned} \frac{d\gamma_o}{dt} = u' \frac{d\gamma_o}{dx'} &= 2\rho' k_f^{(2)} \gamma_{o_2}^2 + 2\rho' k_f^{(1)} \gamma_o \gamma_{o_2} - 2\rho'^2 k_R^{(2)} \gamma_o^2 \gamma_{o_2} \\ &\quad - 2\rho'^2 k_R^{(1)} \gamma_o^3 + 2\rho' \gamma_{o_2} \sum_{i=3}^{5} k_f^{(i)} \gamma_{M_i} - 2\rho'^2 \gamma_o^2 \sum_{i=3}^{5} k_R^{(i)} \gamma_{M_i} \end{aligned} \tag{31}$$

On substituting Eq. (30) and rearranging, Eq. (31) becomes

$$u' \frac{d\gamma_o}{dx'} = 2\rho' K_e k_R^{(2)} \gamma_{o_2}^2 \left\{ 1 - \frac{\rho'}{K_e} \frac{\gamma_o^2}{\gamma_{o_2}} \right\} \left\{ 1 + \beta_1 \frac{\gamma_o}{\gamma_{o_2}} + \sum_{i=3}^{5} \beta_i \frac{\gamma_{M_i}}{\gamma_{o_2}} \right\} \tag{32}$$

where

$$\beta_i = \frac{k_f^{(i)}}{k_f^{(2)}}$$

Now the conservation equation for oxygen atoms is

$$\gamma_O + \gamma_{NO} + 2\gamma_{O_2} = \text{const.}$$

therefore $\gamma_{O_2} = B - \dfrac{\gamma_O}{2}$ where $B = \text{const} - \dfrac{\gamma_{NO}}{2}$

Defining

$$k_R^{(2)} = k_{R_0}^{(2)} T^{-2}$$

$$x = x'/\ell$$

ℓ = length characterizing nozzle geometry

$$= \frac{L}{\alpha} = \frac{\text{half throat height (cm)}}{\text{tangent of nozzle semi-angle}}$$

$$\psi = \frac{2\ell\rho_0'^2}{\sqrt{\frac{R_0 T_0'}{\mu}}} k_{R_0}^{(2)}$$

and substituting in Eq. (32), noting that K_e (Eq. 30) is defined for equilibrium values of the γ_i, there results

$$\frac{d\gamma_O}{dx} = -\frac{\psi\rho^2}{u T^2}\left\{1 + \beta_1\frac{\gamma_O}{\gamma_{O_2}} + \sum_{i=3}^{5}\beta_i\frac{\gamma_{M_i}}{\gamma_{O_2}}\right\}\left\{B - \frac{\gamma_O}{2}\right\} \tag{33}$$

$$\left\{\gamma_O + \frac{B\gamma_{O_e}}{B - \frac{\gamma_{O_e}}{2}}\right\}\left\{\gamma_O - \gamma_{O_e}\right\}$$

where γ_{O_e} = local finite-rate equilibrium value of γ_O, i.e., the equilibrium value of γ_O for the actual temperature and density distribution.

Equation (33) is then of the form introduced by Heims[5]

i.e.,

$$\frac{d\gamma_0}{dx} = -\frac{\gamma_0 - \gamma_{0e}}{r} \tag{34}$$

where

$$r = \frac{r'}{\ell} = \frac{u T^2}{\psi \rho^2 \left\{ 1 + \beta_1 \frac{\gamma_0}{\gamma_{0_2}} + \sum_{i=3}^{5} \beta_1 \frac{\gamma_{M_i}}{\gamma_{0_2}} \right\} \left\{ \beta - \frac{\gamma_0}{2} \right\} \left\{ \gamma_0 + \frac{\beta \gamma_{0_e}}{\beta - \frac{\gamma_{0e}}{2}} \right\}} \tag{35}$$

The rate equation, Eq. (34), which incorporates a local relaxation length r, is used to derive an approximate freezing criterion for the finite-rate flow. The freezing criterion is given in a general form in Ref. 3 and its development is repeated here for completeness.

For flow near equilibrium, $\gamma_0 - \gamma_{0e} << \gamma_{0e}$ and it follows from Eq. (34) that $\left|\frac{d\gamma_0}{dx}\right| << \frac{\gamma_{0e}}{r}$. For near frozen flow, $\gamma_{0e} << \gamma_0$ so that $\left|\frac{d\gamma_0}{dx}\right| \approx \frac{\gamma_0}{r} >> \frac{\gamma_{0e}}{r}$. Thus an indication of where significant freezing has occurred may be obtained by setting $\left|\frac{d\gamma_0}{dx}\right| = \frac{\gamma_{0e}}{r}$. This equality may be evaluated on the basis of the infinite rate equilibrium flow by using the average values of $\frac{d\gamma_0}{dx}$ and γ_0 through the freezing region. That is

$$\frac{d\gamma_0}{dx} = \frac{1}{2}\left(\frac{d\gamma_0}{dx}\right)_\infty$$

$$\gamma_{0e} = \frac{1}{2}(\gamma_0)_\infty$$

to give

$$\left(\frac{d\gamma_0}{dx}\right)_\infty = \frac{\gamma_{0\infty}}{r_\infty} \quad \text{or} \quad \left(\frac{d\gamma_0}{dA}\right)_\infty \left(\frac{dA}{dx}\right) = \frac{\gamma_{0\infty}}{r_\infty} \tag{36}$$

where the subscript ∞ refers to infinite-rate equilibrium values.

Some remarks should be made at this point on the selection of "equilibrium" values. As mentioned earlier in this section, the concept of

a local chemical relaxation length has been found useful for flows in which only a single mode of relaxation is involved, such as the dissociation relaxation of a diatomic gas, with or without inert diluent. For the more complex case of air, the relaxation length criterion has been applied to two simplified kinetic models of air in which the only finite-rate reactions considered are the oxygen dissociation and recombination processes. All species except O and O_2 were assumed to act only as second or third body colliders for the oxygen dissociation-recombination kinetics. The appropriate reaction rate constants were obtained from simple collision theory. Vibrational equilibrium was assumed for all molecular species.

Two basic models were considered in the calculations. In the first, the nitrogen atom and molecule and nitric oxide mass concentrations were frozen at their respective reservoir values during the expansion. In the second, these mass concentrations were taken as those for infinite-rate equilibrium (Sec. II). The flows with oxygen atom-molecule equilibration corresponding to these two models were used in the solution of Eq. (36).

Both models gave values for the frozen degree of oxygen dissociation (α_f) which agreed quite closely up to stagnation temperatures of 6000°K. For example, in a typical hyperbolic nozzle ($L/a = 1.0$) for a stagnation temperature of 5000°K and a stagnation pressure of 100 atm., $\alpha_f = .125$ with N_2, N, and NO frozen at their reservoir concentrations and $\alpha_f = .149$ with N_2, N, and NO in infinite-rate equilibrium. Since these are the limiting conditions for the N_2, N, and NO reactions, this comparison demonstrates that oxygen dissociation-recombination reactions play the major role in air kinetics. The second model has been used in the calculations reported herein, i.e., the equilibrium solutions of Sec. II were used to evaluate relaxation lengths from Eq. (35).

In the above calculations the magnitude of $k_R^{(2)}$ at 3000°K has been taken as 1.16×10^{15} cm^6 mole^{-2} sec^{-1}, from the results of Byron's[8] interferometric studies of oxygen dissociation rates. Then since the temperature dependence of the recombination rate coefficient has been assumed as

$$k_R^{(2)} \sim T^{-2} \qquad \text{(following Ref. 3)}$$

then

$$k_{R_0}^{(2)} = 1.16 \times 10^{15} \left(\frac{3000}{T_0'} \right)^2 \qquad \frac{\text{cm}^6}{\text{mole}^2 \text{ sec}}$$

The remaining rate constants for the second or third bodies (β_i) were determined from ordinary collision theory. The form of the rate coefficient is, from collision theory[9]

$$k_f \sim \frac{K D'^2}{\sigma \sqrt{\mu_{ij}}} \left(\frac{\Theta'_{D_i}}{T'} \right)^{\eta} e^{-\frac{\Theta'_{D_i}}{T'}}$$

where K = steric factor

D' = average diameter of colliding particles

μ_{ij} = reduced mass of colliding particles (i and j)

$$= \frac{\mu_i + \mu_j}{\mu_i \mu_j}$$

η = constant

σ = symmetry number = 1 unlike particles
= 2 like particles

Θ'_{D_i} = characteristic dissociation temperature for species i

For oxygen (from Ref. 8),

$$\frac{k_f^{(1)}}{k_f^{(2)}} = \beta_1 = 35 \frac{T'}{\Theta'_D}$$

For N_2 and NO the steric factors and molecular diameters were assumed the same as for O_2, whence

$$\frac{k_f^{(i)}}{k_f^{(2)}} = \frac{\sigma_2 \sqrt{\mu_{O_2, O_2}}}{\sigma_i \sqrt{\mu_{i, O_2}}}$$

then for N_2,

$$\frac{k_f^{(4)}}{k_f^{(2)}} = \beta_4 = 2.07$$

and NO,

$$\frac{k_f^{(5)}}{k_f^{(2)}} = \beta_5 = 2.033$$

For N, the steric factor and atomic diameter were assumed to be the same as for O, so

$$\frac{k_f^{(3)}}{k_f^{(1)}} = 1.047$$

whence

$$\frac{k_f^{(3)}}{k_f^{(2)}} = \frac{k_f^{(3)}}{k_f^{(1)}} \frac{k_f^{(1)}}{k_f^{(2)}} = 1.047\left(35\frac{T'}{\theta_D'}\right) = 36.6\ \frac{T'}{\theta_D'}$$

Relaxation lengths may then be calculated from Eq. (35).

Equation (36) is solved graphically to locate the point of freezing in the nozzle. The slopes $\left(\frac{d\gamma_0}{dA}\right)_\infty$ are obtained graphically from tangents to the curve of oxygen atom mass concentration as a function of area ratio. Calculated values of $(\gamma_0/r)_\infty$ and the value of $\left(\frac{d\gamma_0}{dA}\right)_\infty \left(\frac{dA}{dx}\right)$ are plotted over a range of area ratios. The area ratio at which these two curves cross is the location at which significant freezing has occurred. The frozen value of γ_0 that can be expected for finite-rate flow is given by the value of $\gamma_{0\infty}$ which corresponds to this area ratio. Figure 18 shows the solution of Eq. (36) for the 5000°K, 100 atm. case.

B. Nozzle Geometry Considered

The nozzle geometries considered are given by the general expression $A = 1 + x^n$. These nozzles are symmetric about the throat for even values of the exponent n. In particular, two nozzle geometries have been considered which correspond to values of the exponent equal to 1 and 2. For $n = 1$, the

nozzle is a simple two-dimensional wedge-type nozzle with a sharp throat. The nozzle parameter, $\ell = L/a$, which enters the equation for the area ratio through the relationship $x = \frac{x'}{L/a}$, is given by one-half the throat height in centimeters divided by the tangent of half the total expansion angle. For $n = 2$, the nozzle is an axisymmetric hyperbolic nozzle with a smooth throat and which becomes a conical nozzle for large values of the area ratio, i.e., for nozzle areas not close to the throat. The nozzle geometry parameter is given by the throat radius in centimeters divided by the tangent of the asymptotic half angle.

The nozzle geometry parameter, L/a, represents the rapidity of the nozzle expansion. For a given throat size, small values of L/a correspond to large expansion angles and therefore to rapidly expanding nozzles. On the other hand, large values of the parameter L/a represent small expansion angles and accordingly correspond to gradually expanding nozzles. Many of the nozzles currently used for hypersonic flow research are designed with a value of L/a of about unity. In the present analyses, values of L/a of 0.1, 1, and 10 have been used to bracket the values of current design practice.

C. Results of Approximate Finite-Rate Solutions

The results of the relaxation length criterion calculations for flow in a hyperbolic axisymmetric and wedge-type nozzle are shown in Figs. 19, 20, and 21. The calculations were performed for stagnation temperatures of 4000, 5000, and 6000°K and stagnation pressures from 100 to 1000 atmospheres, for three values of the nozzle geometry parameter L/a (0.1, 1.0, 10).

Figure 19 shows the area ratio for freezing (A_f) plotted against the stagnation pressure for each stagnation temperature. In all cases freezing occurs fairly early in the nozzle ($A_f < 25$). Further, freezing in the nozzle is delayed by an increase in reservoir pressure, an increase in reservoir temperature, and by the use of gradually expanding nozzles (larger L/a).

The frozen degree of oxygen dissociation, α_f (the mass fraction of oxygen atoms to total oxygen) is given by

$$\alpha_f = \frac{\gamma_{O_f}}{\gamma_{O_f} + \gamma_{NO_f} + 2\gamma_{O_{2f}}}$$

where the subscript f denotes the value at oxygen freezing. The fraction of the stagnation enthalpy represented by frozen chemical energy is given by

$$\frac{H_f}{H_o} = \frac{\mu}{H_o}\left\{ \gamma_{O_f}\frac{\theta_{D_{O_2}}}{2} + \gamma_{N_f}\frac{\theta_{D_{N_2}}}{2} + \gamma_{NO_f}\left(\frac{\theta_{D_{O_2}} + \theta_{D_{N_2}}}{2} - \theta_{D_{NO}}\right)\right\}$$

where

$$\theta_{D_i} = \frac{\theta'_{D_i}}{T_o'}$$

The characteristic dissociation temperatures (θ'_{D_i}) assumed for oxygen, nitrogen and nitric oxide are 59,400°K, 113,200°K, and 75,500°K respectively[7,10].

The frozen degree of dissociation and H_f/H_o are plotted versus the stagnation pressure for each stagnation temperature in Figs. 20 and 21 respectively. Figure 20 shows that the frozen level of oxygen dissociation is appreciably reduced by an increase in stagnation pressure. This indicates that high stagnation pressures are required in order to reduce the static enthalpy loss through freezing at high levels of dissociation. Figure 21 shows, for example, that at a stagnation temperature of 6000°K and a stagnation pressure of 100 atm., as much as 20% of the total enthalpy may be frozen chemical energy. A wedge nozzle is superior to a hyperbolic nozzle of the same L/a because of a lower frozen degree of dissociation.

IV SOLUTIONS FOR EXPANSION AFTER FREEZING

For the simplified kinetic model of air, the exact finite-rate solution is approximated by assuming equilibrium flow up to the freezing point followed by a chemically-frozen flow downstream. This approximation was introduced by Bray[1] for the case of a pure diatomic gas. The area ratio for freezing as determined by the methods outlined in the last section, represents a unique point in the equilibrium solution. The equilibrium gasdynamic properties and composition at this area ratio are the initial values for the subsequent chemically-frozen expansion.

In the frozen expansion calculations, vibrational equilibrium is assumed with the energy taken as that for a quantized linear oscillator. The total gas enthalpy for translational, rotational and vibrational equilibrium, may then be written as

$$
\begin{aligned}
H = 3T + \mu \Bigg[& \gamma_{O_2}\left(\frac{T}{2} + \frac{\theta_{V_{O_2}}}{e^{\theta_{V_{O_2}}/T} - 1}\right) + \gamma_{N_2}\left(\frac{T}{2} + \frac{\theta_{V_{N_2}}}{e^{\theta_{V_{N_2}}/T} - 1}\right) \\
& + \gamma_{NO}\left(\frac{T}{2} + \frac{\theta_{V_{NO}}}{e^{\theta_{V_{NO}}/T} - 1}\right) + \gamma_{O}\left(T + \frac{\theta_{D_{O_2}}}{2}\right) \\
& + \gamma_{N}\left(T + \frac{\theta_{D_{N_2}}}{2}\right) + \gamma_{NO}\left(\frac{\theta_{D_{O_2}} + \theta_{D_{N_2}}}{2} - \theta_{D_{NO}}\right) \Bigg]
\end{aligned}
\tag{37}
$$

where μ = molecular weight undissociated gas (28.85)

$$\theta_{V_i} = \frac{\theta'_{V_i}}{T'_0}$$

The characteristic vibrational temperatures (θ'_{V_i}) used for oxygen, nitrogen and nitric oxide are 2300°K, 3390°K and 2740°K, respectively.

The method of solution is as follows. Since the gas composition is now frozen, all γ_i in Eq. (37) are known constants and the gas enthalpy may be simply determined for any specified temperature ratio T. The velocity is then calculated from Eq. (8).

The frozen expansion is isentropic (by virtue of zero reaction rates [14]), hence

$$dH - \frac{dp}{\rho} = 0 \tag{38}$$

Then from Eq. (10), in which both $\sum \gamma_{i_0}$ and $\sum \gamma_i$ are now constant, we have

$$\int \frac{dH}{T} - \frac{\sum \gamma}{\sum \gamma_{i_0}} \ln T - \frac{\sum \gamma}{\sum \gamma_{i_0}} \ln \rho = \text{CONST.} \tag{39}$$

where $\sum \gamma = \sum \gamma_i$ at freezing

$$= \left(\gamma_{O_2} + \gamma_{N_2} + \gamma_{NO} + \gamma_O + \gamma_N \right)_f$$

Substituting Eq. (37) for H, the left side of Eq. (39) is evaluated to obtain

$$\begin{aligned}
&\frac{1}{\sum \gamma} \left(\frac{3}{\mu} + \frac{\sum \gamma_2}{2} + \sum \gamma_1 - \frac{\sum \gamma}{\mu \sum \gamma_{i_0}} \right) \ln T \\
&+ \frac{\gamma_{O_2}}{\sum \gamma} \left(\frac{1}{T} \frac{\theta_{v_{O_2}}}{e^{\theta_{v_{O_2}}/T} - 1} - \ln \frac{e^{\theta_{v_{O_2}}/T} - 1}{e^{\theta_{v_{O_2}}/T}} \right) \\
&+ \frac{\gamma_{N_2}}{\sum \gamma} \left(\frac{1}{T} \frac{\theta_{v_{N_2}}}{e^{\theta_{v_{N_2}}/T} - 1} - \ln \frac{e^{\theta_{v_{N_2}}/T} - 1}{e^{\theta_{v_{N_2}}/T}} \right) \\
&+ \frac{\gamma_{NO}}{\sum \gamma} \left(\frac{1}{T} \frac{\theta_{v_{NO}}}{e^{\theta_{v_{NO}}/T} - 1} - \ln \frac{e^{\theta_{v_{NO}}/T} - 1}{e^{\theta_{v_{NO}}/T}} \right) - \frac{1}{\mu \sum \gamma_{i_0}} \ln \rho = \text{CONST.}
\end{aligned} \tag{40}$$

where

$$\sum \gamma_2 = (\gamma_{O_2} + \gamma'_{N_2} + \gamma_{NO})_f$$
$$\sum \gamma_1 = (\gamma_O + \gamma_N)_f$$

Equation (40) relates ρ and T explicitly for flow with frozen dissociation and equilibrium vibration. The constant is evaluated initially for equilibrium values at the point of freezing. The density is then calculated from Eq. (40) for all subsequent T. The pressure is next obtained from Eq. (10). Also the area ratio from

$$A = \frac{(\rho u)_*}{\rho u}$$

and a Mach number is calculated at each step from

$$M = u \Big/ \sqrt{\left(\frac{dp}{d\rho}\right)_{\substack{isentropic \\ frozen}}}$$

The frozen air expansions were calculated on the CAL Datatron computer* and the results for all initial reservoir states and all nozzle configurations are tabulated in Tables 17 to 26. The parameters in each table commence with their values at freezing, i.e., the equilibrium values at the appropriate A_f. The behavior of the flow temperature, pressure, density, velocity and Mach number during expansion through the hyperbolic-type nozzles from each initial reservoir state is shown in Figs. 22-31. The corresponding equilibrium solutions are included to show the calculated location of freezing in the nozzle and to provide a basis of comparison for the frozen expansions. Only the results for the extreme nozzle shapes ($\ell = 0.1, 10$) are shown; data for the $\ell = 1.0$ hyperbolic nozzle flows, as well as for all the wedge-type nozzle flows may be extracted from the tables.

*The programming for Datatron machine computation was done by V.L. Widler, Head, Data Handling Section, Hypersonic Tunnel Department, Cornell Aeronautical Laboratory.

V FURTHER KINETIC CONSIDERATIONS

In the application of a relaxation length freezing criterion for air it has been assumed that the freezing of the oxygen kinetics, taken here as the governing chemical mechanism, implies the simultaneous freezing of all kinetics. Actually this assumption has little significance in the present cases since at the predicted freezing temperatures, little dissociation energy exists in the N and NO, and consequently, only a small amount of enthalpy is involved whether these species are assumed to freeze or not.

However, an analysis similar to that outlined in Sec. III may be performed for a different chemical species. The appropriate equations would all be of the same form as those given previously for oxygen. Now if relaxation length considerations were to indicate freezing of this species at area ratios earlier than those predicted in Sec. III on the basis of oxygen kinetics, the previous assumption of simultaneous freezing of all species would result in a greater loss of static enthalpy because of the freezing of oxygen at higher temperatures. This in turn could result in significant changes in some of the gas dynamic properties calculated in Sec. IV. It was considered expedient, therefore, to indicate the approximate solution to a specific case as dictated by the kinetics of some species other than oxygen.

The 6000°K, 100 atmosphere reservoir case was chosen as it involved the greatest amount of initial oxygen dissociation and is therefore the case most sensitive to earlier oxygen freezing. Furthermore, since the equilibrium solution exhibited a more rapid decrease in γ_N compared to γ_O (Fig. 9), the analysis was based on the nitrogen recombination kinetics. Citing only the results, the application of a relaxation length criterion indicated the freezing of nitrogen approximately at the throat for all nozzle configurations. Then, consistent with the previous assumption, the nitric oxide and oxygen were frozen simultaneously with nitrogen and the resultant frozen expansion is indicated by the dashed profiles in Fig. 29.

It is seen that the calculated frozen expansions determined by the nitrogen kinetics may differ appreciably from those determined by oxygen kinetics. The

difference is mainly dependent on the location of oxygen freezing. However, an argument against the freezing of nitrogen is provided by the nitric oxide "shuffle" reactions. The reactions

$$N + NO \underset{slow}{\overset{fast}{\rightleftarrows}} N_2 + O$$

$$N + O_2 \rightleftarrows NO + O$$

provide two fast two-body processes for equilibration of $N - N_2$ and $N - NO$ which have not been considered in the nitrogen three-body processes discussed above.

VI CONCLUSIONS

A method has been described to estimate the effects of finite chemical reaction rates on the one-dimensional expansion of air in hypersonic nozzles. Numerical solutions have been computed for reservoir temperatures from 4000°K to 6000°K and reservoir pressures from 100 to 1000 atmospheres. The calculations have considered a range of wedge and axisymmetric nozzle shapes. The air was assumed to be at rest and in chemical equilibrium at the reservoir state. The flow parameters and gas composition in the infinite-rate equilibrium expansion from each reservoir state were calculated, and a relaxation length criterion, based on the equilibrium solution, was used to indicate the approximate location of freezing for finite-rate airflow in each nozzle configuration. The resultant frozen air expansions have been presented in tabular and graphical form.

The results of the analysis have shown that in all cases, freezing occured fairly early in the nozzle downstream of the throat, at area ratios less than about 25 (Fig. 19). As a result of such early freezing the frozen degree of dissociation may be quite large (Fig. 20) representing an appreciable loss in the static enthalpy. It is seen, for example (Fig. 21), that in the high temperature, low pressure cases, the unavailable enthalpy owing to freezing may be as much as 19% of the stagnation enthalpy.

The following features are evident in the results. The effect of the static enthalpy loss through freezing is to reduce the pressure, velocity and temperature at a particular nozzle location (area ratio) from the corresponding equilibrium values, and to increase the density and Mach number. While the change in temperature and Mach number may be considerable, the density and velocity are relatively unaffected by freezing.

As expected, the effects of freezing are minimized for larger L/a values, i.e., by the use of gradually expanding nozzles. In practice, however, limitations will be imposed by boundary layer growth in the nozzle and a compromise will be required between maximizing L/a and maintaining a reasonable nozzle size. In this respect the wedge nozzle is superior to the hyperbolic nozzle for

a given L/a by virtue of a lower frozen degree of dissociation of the flow (later freezing). It should be noted that the effect of a change in the nozzle L/a parameter also reflects the effect of a change in the kinetic rates, in particular $k_{R_0}^{(2)}$. Since L/a and the recombination rate constant $k_{R_0}^{(2)}$ occur in the rate equation as a product (in ψ), a change in L/a is comparable to a similar change in $k_{R_0}^{(2)}$, the product remaining the same. This factor permits a simple compensation for discrepancies in existing rate constant data. Also noticeable in the results is the reduction in the frozen degree of dissociation with increase in reservoir pressure. This indicates that high reservoir pressures are required in order to reduce the static enthalpy loss through freezing in the operation of hypersonic wind tunnels at high stagnation temperatures. This requirement is compatible with aerodynamic requirements for testing at very high Mach numbers.

The present nonequilibrium airflow calculations are meant as approximate estimates of the gross features of particular finite-rate nozzle flows. In the interests of simplicity several effects have been omitted from the approximations used, notably the neglect of the nitrogen and nitric oxide reactions at finite rates in the simplified kinetic model of air. However, since the assumption of both zero and infinite rates for reactions involving these species resulted in relatively small changes in the frozen levels of dissociation (Sec. 3.1), the calculated expansions from each reservoir state should represent realistic approximations to actual gas behavior in the nozzle. Ultimate verification must come from comparisons with exact solutions to more complex kinetic models. Such a program is presently underway at CAL.

APPENDIX A

NEWTON-RAPHSON METHOD[11,12,13] FOR SOLVING THE EQUILIBRIUM PROBLEM

The use of the Newton-Raphson method for the iterative solution of these simultaneous nonlinear algebraic equations was originally suggested by Brinkley[6] for the determination of equilibrium composition at a given temperature and pressure. Brinkley's method is directly applicable to the computation of the stagnation state; however, certain modifications are introduced for computing composition and pressure at a given entropy for various temperatures along the expansion. Only the modified form is presented here because the essential features of the Brinkley method are contained therein. Equations (23) and (27) are expressed as

$$F_j = 0 \qquad (j = 1, 2, \cdots c, c+1) \tag{A-1}$$

where

$$F_j = q_j + \sum_{\ell = c+1}^{s} \left[q_j (\nu_\ell - 1) - \nu_{\ell j} \right] X_\ell - X_j \tag{A-2}$$

$$(j = 1, 2, \cdots c)$$

$$F_{c+1} = \sum_{i=1}^{s} X_i \left(S_i^\circ - \mu_i s_o - \ln X_i \right) - \ln p' \tag{A-3}$$

For given S_o and T', values of X_j and p' (the ($c+1$)st independent variable) must be guessed such that Equations (A-1) are satisfied. X_ℓ are related to X_j by Equation (24).

$$X_\ell = K_{x_\ell} \prod_{j=1}^{c} X_j^{\nu_{\ell j}} \qquad (\ell = c+1, c+2, \cdots s) \qquad \text{Repeat (24)}$$

The Newton-Raphson method provides a means of improving successive guesses by utilizing a Taylor expansion of F_j about X_j and p' to first order terms. This leads to a set of fractional corrections $h_k^{(r)}$ $(k = 1, 2, \cdots c, c+1)$ applicable to the X_j and p' values obtained at the rth iteration. The improved $(r+1)$st values of the independent variables are found from

$$X_k^{(r+1)} = X_k^{(r)}\left(1 + h_k^{(r)}\right) \qquad (k = 1, 2, \cdots c) \tag{A-4}$$

and

$$p'^{(r+1)} = p'^{(r)}\left(1 + h_{c+1}^{(r)}\right) \tag{A-5}$$

The set of h_k is computed from a set of linear equations expressed in matrix notation by

$$\left[A_{jk}^{(r)}\right]\left[h_k^{(r)}\right] = \left[F_j^{(r)}\right] \qquad \begin{matrix}(j = 1, 2, \cdots c, c+1)\\ (k = 1, 2, \cdots c, c+1)\end{matrix} \tag{A-6}$$

$h_k^{(r)}$ and $F_j^{(r)}$ are column vectors

$$A_{jk} = X_j\,\delta_{jk} + \sum_{\ell=c+1}^{s} \nu_{\ell k}\left[\nu_{\ell j} - q_j\,(\nu_\ell - 1)\right] X_\ell \tag{A-7}$$

$$\delta_{jk} = 0 \quad \text{for} \quad j \neq k \qquad (j = 1, 2, \cdots c)$$

$$\delta_{jk} = 1 \quad \text{for} \quad j = k \qquad (k = 1, 2, \cdots c)$$

$$A_{j,c+1} = \sum_{\ell=c+1}^{s} (\nu_\ell - 1)\left[\nu_{\ell j} - q_j\,(\nu_\ell - 1)\right] X_\ell \qquad (j = 1, 2, \cdots c) \tag{A-8}$$

$$\left.\begin{aligned} A_{c+1,k} = {} & \left[1 - (S_k^\circ - \mu_k\,s_o - \ln X_k)\right] X_k + \\ & \sum_{\ell=c+1}^{s} \nu_{\ell k}\left[1 - (S_\ell^\circ - \mu_\ell\,s_o - \ln X_\ell)\right] X_\ell \end{aligned}\right\} (k = 1, 2, \cdots c) \tag{A-9}$$

$$A_{c+1,c+1} = 1 + \sum_{\ell=c+1}^{s} (\nu_\ell - 1)\left[1 - (S_\ell^\circ - \mu_\ell\,s_o - \ln X_\ell)\right] X_\ell \tag{A-10}$$

The $(r+1)$st iteration is started by calculating $h_k^{(r)}$ from Equation (A-6) using the formulas in Equations (24), (A-2), (A-3), (A-7), (A-8), (A-9), and (A-10). Improved values of X_j and p' are found from Equations (A-4) and (A-5), and improved values of X_ℓ are found from Equation (24) using $X_j^{(r+1)}$ and $p'^{(r+1)}$. The cycle begins again with the computation of $\left[h_k^{(r+1)}\right]$ from Equation (A-6). When all h_k become equal to or smaller than a prescribed maximum fractional error ϵ_h, the computation is terminated.

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T	ρ	p	u' (ft/sec)	M	A	γ_{N_2}	γ_{O_2}	γ_A	γ_N	γ_O	γ_{NO}	$\gamma_{N_2^+}$	$\gamma_{O_2^+}$	γ_{NO^+}	γ_{N^+}	γ_{O^+}	γ_{O^-}	γ_{e^-}
1.00	.100 01	.100 01	.0000 00	.000 00	∞	.2535-01	.4684-02	.3219-03	.5242-05	.1901-02	.3218-02	.2292-13	.4704-10	.1997-07	.6969-16	.9827-13	.4937-08	.1508-07
.98	.896 00	.876 00	.1621 04	.471 00	.1418 01	.2541-01	.4818-02	.3219-03	.4158-05	.1757-02	.3094-02	.1256-13	.3291-10	.1536-07	.4156-16	.5613-13	.3567-08	.1161-07
.96	.801 00	.766 00	.2574 04	.673 00	.1122 01	.2546-01	.4952-02	.3219-03	.3263-05	.1615-02	.2968-02	.6713-14	.2264-10	.1168-07	.1665-16	.3125-13	.2566-08	.9135-08
.94	.715 00	.666 00	.3149 04	.834 00	.1028 01	.2554-01	.5087-02	.3219-03	.2530-05	.1475-02	.2838-02	.3496-14	.1530-10	.8767-08	.8073-17	.1693-13	.1805-08	.6976-08
.92	.636 00	.581 00	.3632 04	.973 00	.1001 01	.2561-01	.5221-02	.3219-03	.1937-05	.1338-02	.2706-02	.1770-14	.1014-10	.6493-08	.3364-17	.8906-14	.1247-08	.5256-08
.90	.566 00	.504 00	.4056 04	.110 01	.1009 01	.2567-01	.5355-02	.3219-03	.1464-05	.1206-02	.2572-02	.8695-15	.6583-11	.4739-08	.1348-17	.4541-14	.6452-09	.3901-08
.88	.502 00	.436 00	.4436 04	.122 01	.1040 01	.2574-01	.5487-02	.3219-03	.1090-05	.1078-02	.2435-02	.4136-15	.4161-11	.3406-08	.5154-18	.2236-14	.5613-09	.2846-08
.86	.444 00	.377 00	.4782 04	.133 01	.1069 01	.2581-01	.5616-02	.3219-03	.7984-06	.9560-03	.2298-02	.1901-15	.2593-11	.2408-08	.1883-18	.1063-14	.3647-09	.2044-08
.84	.393 00	.325 00	.5102 04	.143 01	.1155 01	.2588-01	.5744-02	.3219-03	.5751-06	.8399-03	.2160-02	.8416-16	.1568-11	.1670-08	.6540-19	.4859-15	.2315-09	.1440-08
.82	.347 00	.280 00	.5399 04	.154 01	.1236 01	.2595-01	.5868-02	.3219-03	.4066-06	.7306-03	.2021-02	.3560-16	.9224-12	.1136-08	.2150-19	.2128-15	.1432-09	.9936-09
.80	.306 00	.240 00	.5676 04	.163 01	.1333 01	.2602-01	.5988-02	.3219-03	.2818-06	.6288-03	.1883-02	.1459-16	.5268-12	.7566-09	.6665-20	.8900-16	.8627-10	.6709-09
.78	.269 00	.206 00	.5937 04	.173 01	.1447 01	.2609-01	.6103-02	.3219-03	.1911-06	.5348-03	.1746-02	.5673-17	.2914-12	.4925-09	.1938-20	.3543-16	.5047-10	.4423-09
.76	.237 00	.176 00	.6182 04	.183 01	.1579 01	.2616-01	.6214-02	.3219-03	.1266-06	.4491-03	.1610-02	.2097-17	.1557-12	.3127-09	.5260-21	.1336-16	.2861-10	.2843-09
.74	.208 00	.151 00	.6413 04	.192 01	.1730 01	.2622-01	.6319-02	.3219-03	.8175-07	.3719-03	.1476-02	.7342-18	.8014-13	.1933-09	.1324-21	.4755-17	.1566-10	.1777-09
.72	.182 00	.129 00	.6632 04	.201 01	.1904 01	.2629-01	.6419-02	.3219-03	.5134-07	.3034-03	.1346-02	.2422-18	.3962-13	.1160-09	.3073-22	.1566-17	.8279-11	.1077-09
.70	.161 00	.110 00	.6840 04	.210 01	.2102 01	.2635-01	.6512-02	.3219-03	.3128-07	.2435-03	.1219-02	.7491-19	.1874-13	.6742-10	.6526-23	.4955-18	.4203-11	.6333-10
.68	.1[illegible] 00	.937-01	.7036 04	.219 01	.2327 01	.2641-01	.6600-02	.3219-03	.1844-07	.1920-03	.1096-02	.2159-19	.8450-14	.3785-10	.1259-23	.1453-18	.2043-11	.3561-10
.66	.124 00	.797-01	.7228 04	.228 01	.2584 01	.2647-01	.6680-02	.3219-03	.1048-07	.1485-03	.9777-03	.5765-20	.3617-14	.2046-10	.2186-24	.3820-19	.9477-12	.1951-10
.64	.109 00	.678-01	.7405 04	.236 01	.2676 01	.2653-01	.6755-02	.3219-03	.5730-08	.1125-03	.8652-03	.1415-20	.1462-14	.1061-10	.3381-25	.9312-20	.4176-12	.1019-10
.62	.951-01	.575-01	.7577 04	.245 01	.3210 01	.2658-01	.6823-02	.3219-03	.3000-08	.8323-04	.7587-03	.3166-21	.5556-15	.5257-11	.4609-26	.2058-20	.1740-12	.5084-11
.60	.832-01	.486-01	.7741 04	.254 01	.3590 01	.2663-01	.6884-02	.3219-03	.1498-08	.6007-04	.6588-03	.6402-22	.1971-15	.2478-11	.5466-27	.4065-21	.6815-13	.2410-11
.58	.737-01	.413-01	.7899 04	.263 01	.4027 01	.2666-01	.6940-02	.3219-03	.7099-09	.4217-04	.5659-03	.1157-22	.6488-16	.1106-11	.5565-28	.7201-22	.2495-13	.1061-11
.56	.634-01	.348-01	.8051 04	.273 01	.4529 01	.2672-01	.6989-02	.3219-03	.3175-09	.2872-04	.4804-03							
.54	.552-01	.290-01	.8197 04	.282 01	.5109 01	.2676-01	.7033-02	.3219-03	.1332-09	.1892-04	.4024-03							
.52	.480-01	.243-01	.8339 04	.292 01	.5782 01	.2680-01	.7071-02	.3219-03	.5202-10	.1200-04	.3323-03							
.50	.416-01	.202-01	.8476 04	.302 01	.6566 01	.2683-01	.7105-02	.3219-03	.1876-10	.7303-05	.2699-03							
.48	.359-01	.166-01	.8609 04	.313 01	.7468 01	.2685-01	.7134-02	.3219-03	.6181-11	.4242-05	.2153-03							
.46	.309-01	.136-01	.8736 04	.323 01	.8572 01	.2686-01	.7158-02	.3219-03	.1840-11	.2337-05	.1683-03							
.44	.265-01	.113-01	.8864 04	.335 01	.9662 01	.2690-01	.7179-02	.3219-03	.4881-12	.1213-05	.1285-03							
.42	.226-01	.923-02	.8987 04	.347 01	.1140 02	.2691-01	.7195-02	.3219-03	.1135-12	.5876-06	.9562-04							
.40	.192-01	.745-02	.9106 04	.360 01	.1328 02	.2693-01	.7209-02	.3219-03	.2266-13	.2632-06	.6901-04							
.38	.162-01	.597-02	.9223 04	.373 01	.1553 02	.2694-01	.7219-02	.3219-03	.3797-14	.1077-06	.4810-04							
.36	.135-01	.474-02	.9336 04	.387 01	.1830 02	.2695-01	.7227-02	.3219-03	.5181-15	.3960-07	.3219-04							
.34	.113-01	.373-02	.9446 04	.402 01	.2174 02	.2695-01	.7233-02	.3219-03	.5554-16	.1285-07	.2054-04							
.32	.929-02	.289-02	.9556 04	.419 01	.2606 02	.2696-01	.7237-02	.3219-03	.4468-17	.3595-08	.1238-04							
.30	.759-02	.222-02	.9662 04	.437 01	.3154 02	.2696-01	.7240-02	.3219-03	.2547-18	.8413-09	.6976-05							
.28	.614-02	.167-02	.9767 04	.456 01	.3661 02	.2696-01	.7242-02	.3219-03	.9555-20	.1585-09	.3621-05							
.26	.490-02	.124-02	.9868 04	.477 01	.4787 02	.2696-01	.7243-02	.3219-03	.2141-21	.2285-10	.1699-05							
.24	.385-02	.900-03	.9968 04	.501 01	.6023 02	.2696-01	.7243-02	.3219-03	.2517-23	.2357-11	.7026-06							
.22	.298-02	.638-03	.1007 05	.527 01	.7711 02	.2696-01	.7243-02	.3219-03	.1302-25	.1588-12	.2476-06							
.20	.226-02	.440-03	.1016 05	.557 01	.1007 03	.2696-01	.7244-02	.3219-03	.2316-28	.6138-14	.7085-07							
.18	.167-02	.293-03	.1025 05	.591 01	.1346 03	.2696-01	.7244-02	.3219-03	.9908-32	.1131-15	.1537-07							
.16	.120-02	.187-03	.1035 05	.631 01	.1656 03	.2696-01	.7244-02	.3219-03	.5969-36	.7507-18	.2278-08							
.14	.834-03	.114-03	.1043 05	.679 01	.2857 03	.2696-01	.7244-02	.3219-03		.1158-20	.1963-09							
.12	.552-03	.644-04	.1052 05	.737 01	.3966 03	.2696-01	.7244-02	.3219-03		.1992-24	.7499-11							
.10	.342-03	.333-04	.1061 05	.812 01	.6377 03	.2696-01	.7244-02	.3219-03		.1023-29	.7815-13							

Table 1. EQUILIBRIUM AIRFLOW EXPANSION

$T_o' = 4000°K$, $p_o' = 100$ atm., $\rho_o' = 8.587 \times 10^{-3}$ gm/cm^3,

$H_o = 4.871$, $(\rho u)_* = .6566$ at $T = .916$, $\bar{\mu}_o = 28.18$ gm/mole

T	ρ	P	u' (ft/sec)	M	A	Υ_{N_2}	Υ_{O_2}	Υ_A	Υ_N	Υ_O	Υ_{NO}
1.00	.100 01	.100 01	.0000 00	.000 00	∞	.2530-01	.5015-02	.3219-03	.3007-05	.1130-02	.3327-02
.98	.904 00	.885 00	.1746 04	.452 00	.1462 01	.2537-01	.5130-02	~~.3219-03~~	.2375-05	.1037-02	.3190-02
.96	.815 00	.781 00	.2467 04	.646 00	.1147 01	.2543-01	.5245-02	.3219-03	.1856-05	.9457-03	.3051-02
.94	.734 00	.688 00	.3019 04	.799 00	.1041 01	.2551-01	.5359-02	.3219-03	.1432-05	.8576-03	.2911-02
.92	.656 00	.604 00	.3481 04	.932 00	.1004 01	.2558-01	.5473-02	.3219-03	.1092-05	.7726-03	.2769-02
.90	.592 00	.530 00	.3886 04	.105 01	.1002 01	.2565-01	.5586-02	.3219-03	.8207-06	.6910-03	.2625-02
.88	.531 00	.464 00	.4251 04	.116 01	.1023 01	.2572-01	.5697-02	.3219-03	.6079-06	.6133-03	.2481-02
.86	.475 00	.405 00	.4563 04	.127 01	.1060 01	.2579-01	.5806-02	.3219-03	.4432-06	.5398-03	.2336-02
.84	.424 00	.355 00	.4890 04	.137 01	.1113 01	.2587-01	.5913-02	.3219-03	.3176-06	.4708-03	.2191-02
.82	.378 00	.307 00	.5176 04	.147 01	.1179 01	.2594-01	.6017-02	.3219-03	.2235-06	.4067-03	.2046-02
.80	.337 00	.267 00	.5444 04	.156 01	.1256 01	.2601-01	.6118-02	.3219-03	.1541-06	.3476-03	.1903-02
.78	.300 00	.231 00	.5690 04	.166 01	.1352 01	.2608-01	.6216-02	.3219-03	.1040-06	.2937-03	.1762-02
.76	.266 00	.200 00	.5934 04	.175 01	.1460 01	.2615-01	.6310-02	.3219-03	.6858-07	.2451-03	.1622-02
.74	.236 00	.175 00	.6160 04	.184 01	.1586 01	.2622-01	.6400-02	.3219-03	.4409-07	.2019-03	.1486-02
.72	.209 00	.149 00	.6375 04	.192 01	.1729 01	.2628-01	.6485-02	.3219-03	.2757-07	.1638-03	.1353-02
.70	.185 00	.128 00	.6580 04	.201 01	.1893 01	.2635-01	.6566-02	.3219-03	.1673-07	.1308-03	.1224-02
.68	.164 00	.110 00	.6775 04	.210 01	.2080 01	.2641-01	.6643-02	.3219-03	.9830-08	.1027-03	.1099-02
.66	.145 00	.940-01	.6963 04	.219 01	.2293 01	.2647-01	.6714-02	.3219-03	.5573-08	.7915-04	.9801-03
.64	.127 00	.803-01	.7142 04	.227 01	.2537 01	.2653-01	.6780-02	.3219-03	.3038-08	.5974-04	.8668-03
.62	.112 00	.684-01	.7315 04	.236 01	.2816 01	.2658-01	.6842-02	.3219-03	.1587-08	.4410-04	.7598-03
.60	.984-01	.581-01	.7481 04	.245 01	.3135 01	.2663-01	.6898-02	.3219-03	.7911-09	.3175-04	.6595-03
.58	.862-01	.492-01	.7641 04	.254 01	.3502 01	.2668-01	.6949-02	.3219-03	.3743-09	.2225-04	.5663-03
.56	.754-01	.416-01	.7796 04	.264 01	.3926 01	.2672-01	.6996-02	.3219-03	.1672-09	.1514-04	.4806-03
.54	.656-01	.349-01	.7945 04	.273 01	.4416 01	.2675-01	.7037-02	.3219-03	.7009-10	.9957-05	.4026-03
.52	.572-01	.293-01	.8090 04	.283 01	.4987 01	.2680-01	.7074-02	.3219-03	.2736-10	.6313-05	.3323-03
.50	.496-01	.244-01	.8231 04	.293 01	.5653 01	.2683-01	.7107-02	.3219-03	.9859-11	.3839-05	.2700-03
.48	.429-01	.202-01	.8367 04	.304 01	.6436 01	.2685-01	.7135-02	.3219-03	.3246-11	.2229-05	.2154-03
.46	.369-01	.167-01	.8500 04	.315 01	.7360 01	.2688-01	.7159-02	.3219-03	.9668-12	.1228-05	.1683-03
.44	.316-01	.137-01	.8629 04	.326 01	.8459 01	.2690-01	.7179-02	.3219-03	.2564-12	.6370-06	.1286-03
.42	.270-01	.111-01	.8755 04	.336 01	.9774 01	.2691-01	.7196-02	.3219-03	.5960-13	.3087-06	.9562-04
.40	.229-01	.901-02	.8877 04	.351 01	.1136 02	.2693-01	.7209-02	.3219-03	.1190-13	.1383-06	.6901-04
.38	.193-01	.722-02	.8996 04	.364 01	.1329 02	.2694-01	.7219-02	.3219-03	.1994-14	.5655-07	.4810-04
.36	.162-01	.573-02	.9113 04	.378 01	.1565 02	.2695-01	.7227-02	.3219-03	.2721-15	.2080-07	.3219-04
.34	.135-01	.450-02	.9227 04	.393 01	.1856 02	.2695-01	.7233-02	.3219-03	.2917-16	.6750-08	.2054-04
.32	.111-01	.355-02	.9338 04	.409 01	.2226 02	.2696-01	.7237-02	.3219-03	.2347-17	.1888-08	.1238-04
.30	.907-02	.268-02	.9447 04	.427 01	.2693 02	.2696-01	.7240-02	.3219-03	.1336-18	.4419-09	.6976-05
.28	.733-02	.202-02	.9553 04	.446 01	.3295 02	.2696-01	.7242-02	.3219-03	.5016-20	.8324-10	.3621-05
.26	.585-02	.150-02	.9657 04	.467 01	.4083 02	.2696-01	.7243-02	.3219-03	.1124-21	.1200-10	.1699-05
.24	.460-02	.109-02	.9759 04	.491 01	.5136 02	.2696-01	.7243-02	.3219-03	.1322-23	.1238-11	.7026-06
.22	.356-02	.771-03	.9858 04	.517 01	.6572 02	.2696-01	.7243-02	.3219-03	.6841-26	.6339-13	.2476-06
.20	.270-02	.532-03	.9956 04	.546 01	.8562 02	.2696-01	.7244-02	.3219-03	.1217-28	.3224-14	.7085-07
.18	.200-02	.354-03	.1005 05	.580 01	.1146 03	.2696-01	.7244-02	.3219-03	.5204-32	.5939-16	.1537-07
.16	.144-02	.226-03	.1014 05	.619 01	.1582 03	.2696-01	.7244-02	.3219-03	.3135-36	.3943-18	.2278-08
.14	.997-03	.137-03	.1023 05	.666 01	.2262 03	.2696-01	.7244-02	.3219-03		.6080-21	.1963-09
.12	.659-03	.776-04	.1032 05	.724 01	.3391 03	.2696-01	.7244-02	.3219-03		.1047-24	.7499-11
.10	.409-03	.402-04	.1041 05	.797 01	.5424 03	.2696-01	.7244-02	.3219-03		.5373-30	.7815-13

T	$\Upsilon_{N_2^+}$	$\Upsilon_{O_2^+}$	Υ_{NO^+}	Υ_{N^+}	Υ_{O^+}	Υ_{O^-}	Υ_{e^-}
1.00	.1414-13	.3115-10	.1276-07	.5160-16	.3609-13	.4746-08	.8043-08
.98	.7691-14	.2150-10	.9717-08	.1456-16	.2032-13	.3449-08	.6290-08
.96	.4082-14	.1460-10	.7313-08	.6460-17	.1115-13	.2460-08	[illegible]
.94	.2109-14	.9737-11	.5434-08	.2762-17	.5949-14	.1737-08	.3707-08
.92	.1060-14	.6370-11	.3962-08	.1136-17	.3062-14	[illegible]	.2788-08
.90	.5163-15	.4082-11	.2876-08	.4467-18	.1547-14	.8147-09	.2065-08
.88	.2436-15	.2559-11	.2045-08	.1695-18	.7504-15	.5410-09	.1550-08
.86	.1110-15	.1567-11	.1429-08	.6110-19	.3510-15	.3525-09	[illegible]
.84	.4874-16	.9354-12	.9614-09	.2093-19	.1576-15	.2259-09	.7384-09
.82	.2056-16	.5435-12	.6606-09	.6790-20	.6805-16	[illegible]	.5125-09
.80	.8308-17	.3067-12	.4356-09	.2070-20	.2803-16	.8372-10	[illegible]
.78	.3204-17	.1677-12	.2808-09	.5959-21	.1099-16	.4900-10	.2319-09
.76	.1175-17	.8862-13	.1766-09	.1597-21	.4069-17	.2760-10	[illegible]
.74	.4063-18	.4514-13	.1082-09	.3972-22	.1435-17	[illegible]	[illegible]
.72	.1337-18	.2210-13	.6436-10	.9113-23	.4735-18	.8045-11	[illegible]
.70	.4108-19	.1036-13	.3712-10	.1915-23	.1459-18	.4116-11	[illegible]
.68	.1177-19	.4634-14	.2069-10	.3656-24	.4177-19	.2026-11	[illegible]
.66	.3123-20	.1969-14	.1111-10	.6295-25	.1103-19	.9325-12	.1010-10
.64	.7624-21	.7911-15	.5728-11	.9661-26	.2666-20	.4116-12	.5317-11
.62	.1698-21	.2969-15	.2624-11	.1306-26	.5649-21	.1745-12	[illegible]
.60	.3420-22	.1055-15	.1326-11	.1543-27	.1154-21	[illegible]	[illegible]
.58	.6162-23	.3459-16	.5692-12	.1562-28	.2023-22	.2474-13	[illegible]

Table 2. EQUILIBRIUM AIRFLOW EXPANSION

$T_o' = 4000°K$, $p_o' = 300$ atm., $\rho_o' = 2.604 \times 10^{-2}$ gm/cm^3,
$H_o = 4.705$, $(\rho u)_* = .6551$ at $T = .909$, $\overline{\mu}_o = 28.50$ gm/mole

T [19]	ρ	p	u' (ft/sec)	M	A	γ_{N_2}	γ_{O_2}	γ_A	γ_N	γ_O	γ_{NO}
1.00	.100 01	.100 01	.0000 00	.000 00	∞	.2526-01	.5231-02	.3219-03	.1640-05	.6296-03	.3395-02
.98	.910 00	.891 00	.1689 04	.437 00	.1501 01	.2534-01	.5331-02	.3219-03	.1291-05	.5747-03	.3250-02
.96	.826 00	.792 00	.2386 04	.624 00	.1170 01	.2541-01	.5431-02	.3219-03	.1005-05	.5217-03	.3104-02
.94	.749 00	.703 00	.2920 04	.772 00	.1054 01	.2548-01	.5530-02	.3219-03	.7735-06	.4706-03	.2956-02
.92	.676 00	.622 00	.3366 04	.900 00	.1010 01	.2556-01	.5629-02	.3219-03	.5875-06	.4218-03	.2807-02
.90	.613 00	.550 00	.3761 04	.102 01	.1000 01	.2563-01	.5727-02	.3219-03	.4401-06	.3753-03	.2657-02
.88	.553 00	.485 00	.4114 04	.112 01	.1013 01	.2571-01	.5824-02	.3219-03	.3249-06	.3315-03	.2508-02
.86	.496 00	.427 00	.4438 04	.123 01	.1043 01	.2578-01	.5919-02	.3219-03	.2360-06	.2904-03	.2358-02
.84	.446 00	.374 00	.4737 04	.132 01	.1066 01	.2586-01	.6013-02	.3219-03	.1686-06	.2521-03	.2209-02
.82	.402 00	.328 00	.5016 04	.142 01	.1141 01	.2593-01	.6105-02	.3219-03	.1182-06	.2168-03	.2061-02
.80	.361 00	.287 00	.5279 04	.151 01	.1211 01	.2600-01	.6194-02	.3219-03	.8128-07	.1845-03	.1915-02
.78	.322 00	.250 00	.5527 04	.160 01	.1292 01	.2608-01	.6281-02	.3219-03	.5469-07	.1553-03	.1771-02
.76	.288 00	.218 00	.5761 04	.169 01	.1388 01	.2615-01	.6364-02	.3219-03	.3596-07	.1291-03	.1629-02
.74	.257 00	.189 00	.5985 04	.178 01	.1498 01	.2622-01	.6445-02	.3219-03	.2305-07	.1059-03	.1491-02
.72	.229 00	.164 00	.6198 04	.167 01	.1624 01	.2626-01	.6522-02	.3219-03	.1438-07	.8570-04	.1356-02
.70	.204 00	.141 00	.6402 04	.195 01	.1769 01	.2635-01	.6596-02	.3219-03	.8710-08	.6826-04	.1226-02
.68	.181 00	.122 00	.6598 04	.204 01	.1934 01	.2641-01	.6666-02	.3219-03	.5107-08	.5346-04	.1101-02
.66	.160 00	.105 00	.6785 04	.213 01	.2124 01	.2647-01	.6732-02	.3219-03	.2890-08	.4111-04	.9815-03
.64	.141 00	.897-01	.6966 04	.221 01	.2341 01	.2653-01	.6794-02	.3219-03	.1574-08	.3097-04	.8677-03
.62	.125 00	.767-01	.7140 04	.230 01	.2590 01	.2656-01	.6852-02	.3219-03	.8210-09	.2283-04	.7603-03
.60	.110 00	.653-01	.7306 04	.239 01	.2675 01	.2663-01	.6903-02	.3219-03	.4088-09	.1642-04	.6598-03
.58	.964-01	.554-01	.7470 04	.248 01	.3204 01	.2666-01	.6955-02	.3219-03	.1933-09	.1149-04	.5665-03
.56	.844-01	.468-01	.7627 04	.258 01	.3565 01	.2672-01	.6999-02	.3219-03	.8629-10	.7812-05	.4807-03
.54	.736-01	.394-01	.7779 04	.267 01	.4026 01	.2676-01	.7040-02	.3219-03	.3615-10	.5136-05	.4026-03
.52	.641-01	.330-01	.7926 04	.277 01	.4540 01	.2680-01	.7076-02	.3219-03	.1410-10	.3255-05	.3324-03
.50	.556-01	.276-01	.8069 04	.287 01	.5140 01	.2683-01	.7108-02	.3219-03	.5082-11	.1979-05	.2700-03
.48	.481-01	.229-01	.8208 04	.296 01	.5846 01	.2685-01	.7135-02	.3219-03	.1674-11	.1149-05	.2154-03
.46	.414-01	.189-01	.8343 04	.309 01	.6680 01	.2688-01	.7159-02	.3219-03	.4982-12	.6326-06	.1683-03
.44	.355-01	.155-01	.8475 04	.320 01	.7672 01	.2690-01	.7179-02	.3219-03	.1321-12	.3282-06	.1286-03
.42	.303-01	.126-01	.8602 04	.332 01	.8860 01	.2691-01	.7196-02	.3219-03	.3071-13	.1590-06	.9562-04
.40	.257-01	.102-01	.8727 04	.345 01	.1029 02	.2693-01	.7209-02	.3219-03	.6133-14	.7124-07	.6901-04
.38	.217-01	.816-02	.8848 04	.356 01	.1203 02	.2694-01	.7219-02	.3219-03	.1028-14	.2914-07	.4810-04
.36	.162-01	.646-02	.8967 04	.372 01	.1417 02	.2695-01	.7227-02	.3219-03	.1402-15	.1072-07	.3219-04
.34	.151-01	.509-02	.9083 04	.387 01	.1681 02	.2695-01	.7233-02	.3219-03	.1503-16	.3478-08	.2054-04
.32	.125-01	.395-02	.9196 04	.403 01	.2013 02	.2696-01	.7237-02	.3219-03	.1209-17	.9729-09	.1238-04
.30	.102-01	.303-02	.9306 04	.421 01	.2435 02	.2696-01	.7240-02	.3219-03	.6893-19	.2277-09	.6976-05
.28	.823-02	.226-02	.9414 04	.440 01	.2976 02	.2696-01	.7242-02	.3219-03	.2586-20	.4288-10	.3621-05
.26	.657-02	.169-02	.9519 04	.461 01	.3689 02	.2696-01	.7243-02	.3219-03	.5793-22	.6183-11	.1699-05
.24	.517-02	.123-02	.9623 04	.484 01	.4639 02	.2696-01	.7243-02	.3219-03	.6812-24	.6379-12	.7026-06
.22	.400-02	.871-03	.9724 04	.510 01	.5934 02	.2696-01	.7243-02	.3219-03	.3524-26	.4297-13	.2476-06
.20	.303-02	.601-03	.9822 04	.539 01	.7747 02	.2696-01	.7244-02	.3219-03	.6268-29	.1661-14	.7085-07
.18	.224-02	.400-03	.9919 04	.572 01	.1036 03	.2696-01	.7244-02	.3219-03	.2681-32	.3060-16	.1537-07
.16	.161-02	.256-03	.1001 05	.611 01	.1427 03	.2696-01	.7244-02	.3219-03	.1615-36	.2031-18	.2278-08
.14	.112-02	.155-03	.1011 05	.658 01	.2040 03	.2696-01	.7244-02	.3219-03		.3132-21	.1963-09
.12	.740-03	.880-04	.1020 05	.714 01	.3058 03	.2696-01	.7244-02	.3219-03		.5392-25	.7499-11
.10	.459-03	.454-04	.1028 05	.767 01	.4890 03	.2696-01	.7244-02	.3219-03		.2768-30	.7815-13

T [19]	$\gamma_{N_2^+}$	$\gamma_{O_2^+}$	γ_{NO^+}	γ_{N^+}	γ_{O^+}	γ_{O^-}	γ_{e^-}
1.00	.8772-14	.2018-10	.8092-08	.1078-16	.1250-13	.4257-08	.3855-08
.98	.4737-14	.1378-10	.6105-08	.4686-17	.6948-14	.3101-08	.3018-08
.96	.2495-14	.9249-11	.4550-08	.2141-17	.3762-14	.2225-08	.2335-08
.94	.1279-14	.6096-11	.3346-08	.9049-18	.1961-14	.1571-08	.1783-08
.92	.6369-15	.3941-11	.2429-08	.3679-18	.1012-14	.1090-08	.1343-08
.90	.3077-15	.2496-11	.1736-08	.1435-18	.5011-15	.7421-09	.9966-09
.88	.1439-15	.1546-11	.1222-08	.5355-19	.2397-15	.4953-09	.7279-09
.86	.6500-16	.9357-12	.8452-09	.1906-19	.1106-15	.3256-09	.5226-09
.84	.2828-16	.5521-12	.5743-09	.6448-20	.4904-16	.2065-09	.3683-09
.82	.1162-16	.3171-12	.3627-09	.2066-20	.2086-16	.1266-09	.2544-09
.80	.4733-17	.1769-12	.2496-09	.6240-21	.6476-17	.7797-10	.1720-09
.78	.1809-17	.9567-13	.1594-09	.1770-21	.3262-17	.4592-10	.1136-09
.76	.6578-18	.5003-13	.9927-10	.4666-22	.1205-17	.2621-10	.7310-10
.74	.2266-18	.2523-13	.6023-10	.1153-22	.4180-18	.1447-10	.4579-10
.72	.7359-19	.1223-13	.3552-10	.2616-23	.1363-18	.7696-11	.2764-10
.70	.2243-19	.5682-14	.2031-10	.5443-24	.4157-19	.3935-11	.1636-10
.68	.6376-20	.2520-14	.1123-10	.1030-24	.1176-19	.1926-11	.9302-11
.66	.1680-20	.1063-14	.5987-11	.1757-25	.3082-20	.8997-12	.5089-11
.64	.4077-21	.4239-15	.3066-11	.2675-26	.7390-21	.3991-12	.2667-11
.62	.9028-22	.1591-15	.1502-11	.3597-27	.1610-21	.1673-12	.1335-11
.60	.1809-22	.5586-16	.7012-12	.4215-28	.3154-22	.6593-13	.6354-12

Table 3. EQUILIBRIUM AIRFLOW EXPANSION

$T_o' = 4000°K$, $p_o' = 1000$ atm., $\rho_o' = 8.744 \times 10^{-2}$ gm/cm^3,
$H_o = 4.599$, $(\rho u)_* = .6547$ at $T = .903$, $\bar{\mu}_o = 28.70$ gm/mole

20 T	ρ	p	u' (ft/sec)	M	A	τ_{N_2}	τ_{O_2}	τ_A	τ_N	τ_O	τ_{NO}
1.00	.100 01	.100 01	.0000 00	.000 00	~	.2505-01	.2208-02	.3219-03	.1006-03	.6340-02	.3731-02
.98	.899 00	.878 00	.2081 04	.465 00	.1430 01	.2508-01	.2339-02	.3219-03	.8434-04	.6126-02	.3682-02
.96	.805 00	.708 00	.2951 04	.667 00	.1126 01	.2511-01	.2479-02	.3219-03	.7019-04	.5902-02	.3627-02
.94	.718 00	.669 00	.3624 04	.830 00	.1029 01	.2515-01	.2627-02	.3219-03	.5794-04	.5667-02	.3565-02
.92	.636 00	.579 00	.4195 04	.974 00	.1001 01	.2519-01	.2784-02	.3219-03	.4742-04	.5421-02	.3498-02
.90	.563 00	.499 00	.4703 04	.111 01	.1010 01	.2523-01	.2949-02	.3219-03	.3845-04	.5166-02	.3423-02
.88	.496 00	.427 00	.5165 04	.123 01	.1046 01	.2528-01	.3122-02	.3219-03	.3087-04	.4902-02	.3342-02
.86	.434 00	.364 00	.5593 04	.136 01	.1103 01	.2532-01	.3303-02	.3219-03	.2453-04	.4628-02	.3253-02
.84	.378 00	.306 00	.5995 04	.147 01	.1183 01	.2537-01	.3492-02	.3219-03	.1926-04	.4347-02	.3156-02
.82	.327 00	.260 00	.6374 04	.159 01	.1285 01	.2543-01	.3688-02	.3219-03	.1494-04	.4059-02	.3052-02
.80	.281 00	.217 00	.6734 04	.171 01	.1412 01	.2549-01	.3890-02	.3219-03	.1143-04	.3766-02	.2941-02
.78	.241 00	.181 00	.7077 04	.182 01	.1569 01	.2555-01	.4098-02	.3219-03	.8611-05	.3469-02	.2822-02
.76	.205 00	.149 00	.7405 04	.194 01	.1761 01	.2561-01	.4311-02	.3219-03	.6385-05	.3169-02	.2696-02
.74	.174 00	.123 00	.7720 04	.205 01	.1994 01	.2566-01	.4527-02	.3219-03	.4651-05	.2870-02	.2563-02
.72	.147 00	.100 00	.8022 04	.217 01	.2277 01	.2575-01	.4745-02	.3219-03	.3321-05	.2572-02	.2424-02
.70	.123 00	.813-01	.8312 04	.229 01	.2620 01	.2582-01	.4964-02	.3219-03	.2320-05	.2279-02	.2280-02
.68	.103 00	.657-01	.8589 04	.240 01	.3037 01	.2590-01	.5181-02	.3219-03	.1582-05	.1994-02	.2131-02
.66	.854-01	.528-01	.8855 04	.252 01	.3541 01	.2597-01	.5395-02	.3219-03	.1050-05	.1719-02	.1978-02
.64	.706-01	.423-01	.9108 04	.263 01	.4150 01	.2605-01	.5603-02	.3219-03	.6758-06	.1458-02	.1823-02
.62	.580-01	.338-01	.9350 04	.275 01	.4885 01	.2613-01	.5804-02	.3219-03	.4207-06	.1213-02	.1666-02
.60	.474-01	.270-01	.9579 04	.286 01	.5766 01	.2621-01	.5994-02	.3219-03	.2523-06	.9892-03	.1509-02
.58	[illegible]	[illegible]	.9796 04	.298 01	.6825 01	.2628-01	.6173-02	.3219-03	.1450-06	.7876-03	.1354-02
.56	[illegible]	.171-01	.1000 05	.309 01	.8084 01	.2636-01	.6337-02	.3219-03	.7953-07	.6108-03	.1202-02
.54	.274-01	.136-01	.1019 05	.320 01	.9577 01	.2643-01	.6486-02	.3219-03	.4137-07	.4598-03	.1055-02
.52	.227-01	.109-01	.1037 05	.332 01	.1134 02	.2650-01	.6619-02	.3219-03	.2029-07	.3350-03	.9139-03
.50	.189-01	.866-02	.1054 05	.343 01	.1342 02	.2657-01	.6736-02	.3219-03	.9314-08	.2353-03	.7807-03
.48	.156-01	.693-02	.1070 05	.354 01	.1586 02	.2663-01	.6838-02	.3219-03	.3970-08	.1586-03	.6565-03
.46	[illegible]	[illegible]	.1085 05	.365 01	.1875 02	.2669-01	.6921-02	.3219-03	.1557-08	.1022-03	.5426-03
.44	.110-01	.442-02	.1100 05	.377 01	.2217 02	.2674-01	.6992-02	.3219-03	.5556-09	.6263-04	.4398-03
.42	.915-02	.352-02	.1114 05	.390 01	.2625 02	.2679-01	.7051-02	.3219-03	.1781-09	.3624-04	.3488-03
.40	.762-02	.279-02	.1127 05	.403 01	.3116 02	.2683-01	.7099-02	.3219-03	.5051-10	.1966-04	.2698-03
.38	.632-02	.220-02	.1140 05	.416 01	.3714 02	.2686-01	.7137-02	.3219-03	.1244-10	.9904-05	.2028-03
.36	.522-02	.172-02	.1152 05	.431 01	.4449 02	.2689-01	.7167-02	.3219-03	.2597-11	.4579-05	.1475-03
.34	.429-02	.133-02	.1164 05	.447 01	.5365 02	.2691-01	.7191-02	.3219-03	.4471-12	.1915-05	.1032-03
.32	.349-02	.102-02	.1175 05	.464 01	.6520 02	.2693-01	.7209-02	.3219-03	.6120-13	.7109-06	.6901-04
.30	.282-02	.774-03	.1187 05	.483 01	.7997 02	.2694-01	.7222-02	.3219-03	.6362-14	.2289-06	.4368-04
.28	.225-02	.577-03	.1198 05	.503 01	.9916 02	.2695-01	.7231-02	.3219-03	.4734-15	.6197-07	.2588-04
.26	.178-02	.423-03	.1208 05	.526 01	.1245 03	.2695-01	.7236-02	.3219-03	.2334-16	.1356-07	.1413-04
.24	.138-02	.304-03	.1219 05	.551 01	.1586 03	.2696-01	.7240-02	.3219-03	.6879-18	.2272-08	.6976-05
.22	.106-02	.213-03	.1229 05	.579 01	.2057 03	.2696-01	.7242-02	.3219-03	.1052-19	.2711-09	.3028-05
.20	.793-03	.145-03	.1239 05	.611 01	.2721 03	.2696-01	.7243-02	.3219-03	.6662-22	.2077-10	.1112-05
.18	.580-03	.956-04	.1249 05	.646 01	.3691 03	.2696-01	.7243-02	.3219-03	.1434-24	.6816-12	.3270-06
.16	.412-03	.603-04	.1259 05	.691 01	.5159 03	.2696-01	.7244-02	.3219-03	.6255-28	.1658-13	.7085-07
.14	.282-03	.361-04	.1268 05	.742 01	.7488 03	.2696-01	.7244-02	.3219-03	.2909-32	.9725-16	.9932-08
.12	.184-03	.202-04	.1277 05	.804 01	.1141 04	.2696-01	.7244-02	.3219-03		.9912-19	.7254-09
.10	.112-03	.103-04	.1286 05	.884 01	.1856 04	.2696-01	.7244-02	.3219-03		.6113-23	.1870-10
.08	.624-04	.456-05	.1295 05	.991 01	.3314 04	.2696-01	.7244-02	.3219-03		.2763-29	.7815-13
.06	.300-04	.165-05	.1303 05	.115 02	.6646 04	.2696-01	.7244-02	.3219-03			.8645-17
.04	.111-04	.405-06	.1312 05	.141 02	.1841 05	.2696-01	.7244-02	.3219-03			.1111-24
.02	.216-05	.396-07	.1320 05	.199 02	.9377 05	.2696-01	.7244-02	.3219-03			

20 T	$\tau_{N_2^+}$	$\tau_{O_2^+}$	τ_{NO^+}	τ_{N^+}	τ_{O^+}	τ_{O^-}	τ_{e^-}
1.00	.1734-10	.1927-08	.4176-06	.6664-12	.7350-10	.8655-07	.3331-06
.98	.1066-10	.1504-08	.3445-06	.3641-12	.4836-10	.6692-07	.2772-06
.96	.6451-11	.1160-08	.2818-06	.1940-12	.3126-10	.5425-07	.2288-06
.94	.3819-11	.8626-09	.2285-06	.1007-12	.1980-10	.4217-07	.1872-06
.92	.2212-11	.6622-09	.1834-06	.5081-13	.1229-10	.3234-07	.1516-06
.90	.1252-11	.4694-09	.1458-06	.2486-13	.7452-11	.2445-07	[illegible]
.88	.6914-12	.3556-09	.1146-06	.1180-13	.4412-11	.1820-07	.9672-07
.86	.3719-12	.2542-09	.8896-07	.5404-14	.2546-11	.1331-07	.7591-07
.84	.1945-12	.1782-09	.6821-07	.2386-14	.1428-11	.9536-08	.5682-07
.82	.9873-13	.1224-09	.5157-07	.1012-14	.7777-12	.6726-08	[illegible]
.80	.4850-13	.8224-10	.3841-07	.4115-15	.4096-12	[illegible]	[illegible]
.78	.2300-13	.5394-10	.2814-07	.1596-15	.2084-12	.3130-08	[illegible]
.76	.1050-13	.3447-10	.2025-07	.5887-16	.1019-12	[illegible]	[illegible]
.74	.4600-14	.2141-10	[illegible]	.2054-16	.4780-13	.1318-08	[illegible]
.72	.1926-14	.1289-10	.9869-08	.6746-17	.2139-13	.8181-09	[illegible]
.70	.7676-15	.7496-11	.6655-08	.2073-17	.9096-14	.4952-09	[illegible]
.68	.2696-15	.4200-11	.4371-08	.5921-18	.3654-14	[illegible]	[illegible]
.66	.1031-15	.2258-11	.2789-08	.1560-18	.1379-14	.1589-09	[illegible]
.64	.3434-16	.1159-11	.1722-08	.3758-19	.4852-15	[illegible]	[illegible]
.62	.1064-16	.5656-12	.1026-08	.8199-20	.1580-15	.4346-10	[illegible]
.60	.3041-17	.2611-12	.5869-09	.1602-20	.4719-16	.2113-10	[illegible]
.58	.7950-18	.1132-12	.3210-09	.2767-21	.1280-16	.9711-11	[illegible]
.56	.1881-18	.4577-13	.1670-09	.4167-22	.3116-17	[illegible]	[illegible]
.54	.3983-19	.1714-13	.6211-10	.5385-23	.6726-18	.1695-11	[illegible]
.52	.7446-20	.5887-14	.3792-10	.5862-24	.1272-18	.6347-12	[illegible]
.50	.1212-20	.1636-14	.1633-10	.5267-25	.2068-19	.2184-12	[illegible]
.48	.1685-21	.5152-15	.6501-11	.3814-26	.2840-20	.6618-13	[illegible]
.46	.1964-22	.1281-15	.2369-11	.2166-27	.3227-21	.1925-13	[illegible]
.44	.1872-23	.2760-16	.7617-12		.2960-22	.4603-14	[illegible]

Table 4. EQUILIBRIUM AIRFLOW EXPANSION

$T_o' = 5000°K$, $p_o' = 100$ atm., $\rho_o' = 6.457 \times 10^{-3}$ gm/cm^3,

$H_o = 5.676$, $(\rho u)_* = .6794$ at $T = .916$, $\overline{\mu}_o = 26.$[illegible] gm/mole

T[32]	ρ	P	u' (ft/sec)	M	A	T_{N_2}	T_{O_2}	T_A	T_N	T_O	T_{NO}
1.00	.100 01	.100 01	.0000 00	.000 00	∞	.2486-01	.2718-02	.3219-03	.7019-04	.4926-02	.4125-02
.98	.900 00	.880 00	.2051 04	.403 00	.1436 01	.2491-01	.2851-02	~~.3219~~-03	.5883-04	.4734-02	.4051-02
.96	.807 00	.770 00	.2906 04	.663 00	.1130 01	.2495-01	.2991-02	.3219-03	.4894-04	.4534-02	.3971-02
.94	.721 00	.672 00	.3560 04	.824 00	.1031 01	.2500-01	.3138-02	.3219-03	.4037-04	.4327-02	.3885-02
.92	.642 00	.584 00	.4125 04	.966 00	.1001 01	.2505-01	.3290-02	.3219-03	.3301-04	.4114-02	.3792-02
.90	.569 00	.505 00	.4621 04	.110 01	.1006 01	.2510-01	.3450-02	.3219-03	.2673-04	.3894-02	.3693-02
.88	.502 00	.434 00	.5071 04	.122 01	.1041 01	.2516-01	.3615-02	.3219-03	.2143-04	.3669-02	.3587-02
.86	.441 00	.372 00	.5486 04	.134 01	.1094 01	.2522-01	.3786-02	.3219-03	.1699-04	.3439-02	.3475-02
.84	.386 00	.317 00	.5875 04	.145 01	.1166 01	.2528-01	.3963-02	.3219-03	.1331-04	.3206-02	.3356-02
.82	.337 00	.269 00	.6240 04	.157 01	.1262 01	.2534-01	.4144-02	.3219-03	.1029-04	.2969-02	.3230-02
.80	.292 00	.226 00	.6580 04	.166 01	.1378 01	.2541-01	.4329-02	.3219-03	.7843-05	.2731-02	.3097-02
.78	.252 00	.190 00	.6915 04	.179 01	.1520 01	.2548-01	.4518-02	.3219-03	.5888-05	.2493-02	.2959-02
.76	.217 00	.159 00	.7229 04	.190 01	.1691 01	.2555-01	.4708-02	.3219-03	.4345-05	.2257-02	.2814-02
.74	.186 00	.132 00	.7526 04	.201 01	.1896 01	.2563-01	.4900-02	.3219-03	.3148-05	.2023-02	.2664-02
.72	.156 00	.109 00	.7815 04	.212 01	.2141 01	.2571-01	.5092-02	.3219-03	.2235-05	.1794-02	.2509-02
.70	.135 00	.899-01	.8089 04	.223 01	.2433 01	.2579-01	.5282-02	.3219-03	.1551-05	.1573-02	.2350-02
.68	.114 00	.736-01	.8351 04	.234 01	.2782 01	.2587-01	.5469-02	.3219-03	.1050-05	.1360-02	.2188-02
.66	.964-01	.603-01	.8601 04	.244 01	.3196 01	.2595-01	.5652-02	.3219-03	.6913-06	.1159-02	.2024-02
.64	.815-01	.492-01	.8840 04	.255 01	.3689 01	.2603-01	.5829-02	.3219-03	.4415-06	.9716-03	.1856-02
.62	.684-01	.400-01	.9067 04	.266 01	.4272 01	.2611-01	.5997-02	.3219-03	.2726-06	.7993-03	.1693-02
.60	.575-01	.325-01	.9283 04	.277 01	.4961 01	.2620-01	.6157-02	.3219-03	.1621-06	.6441-03	.1529-02
.58	.484-01	.264-01	.9488 04	.287 01	.5775 01	.2628-01	.6306-02	.3219-03	.9238-07	.5072-03	.1369-02
.56	.407-01	.213-01	.9685 04	.298 01	.6733 01	.2636-01	.6443-02	.3219-03	.5025-07	.3892-03	.1212-02
.54	.342-01	.173-01	.9868 04	.309 01	.7858 01	.2643-01	.6568-02	.3219-03	.2595-07	.2902-03	.1062-02
.52	.287-01	.140-01	.1004 05	.320 01	.9181 01	.2650-01	.6680-02	.3219-03	.1264-07	.2097-03	.9181-03
.50	.242-01	.113-01	.1021 05	.331 01	.1074 02	.2657-01	.6779-02	.3219-03	.5769-08	.1462-03	.7832-03
.48	.203-01	.912-02	.1037 05	.342 01	.1257 02	.2663-01	.6866-02	.3219-03	.2447-08	.9801-04	.6579-03
.46	.171-01	.734-02	.1052 05	.353 01	.1474 02	.2669-01	.6940-02	.3219-03	.9561-09	.6287-04	.5434-03
.44	.144-01	.589-02	.1066 05	.365 01	.1732 02	.2674-01	.7004-02	.3219-03	.3402-09	.3839-04	.4402-03
.42	.120-01	.471-02	.1080 05	.377 01	.2042 02	.2679-01	.7058-02	.3219-03	.1089-09	.2216-04	.3490-03
.40	.100-01	.374-02	.1094 05	.390 01	.2416 02	.2683-01	.7103-02	.3219-03	.3083-10	.1200-04	.2699-03
.38	.834-02	.295-02	.1106 05	.404 01	.2873 02	.2686-01	.7139-02	.3219-03	.7585-11	.6041-05	.2029-03
.36	.689-02	.231-02	.1119 05	.419 01	.3436 02	.2689-01	.7168-02	.3219-03	.1583-11	.2791-05	.1475-03
.34	.566-02	.179-02	.1131 05	.434 01	.4139 02	.2691-01	.7191-02	.3219-03	.2725-12	.1167-05	.1032-03
.32	.461-02	.138-02	.1143 05	.452 01	.5026 02	.2693-01	.7209-02	.3219-03	.3729-13	.4332-06	.6901-04
.30	.373-02	.104-02	.1155 05	.470 01	.6161 02	.2694-01	.7222-02	.3219-03	.3876-14	.1394-06	.4368-04
.28	.298-02	.777-03	.1166 05	.490 01	.7635 02	.2695-01	.7231-02	.3219-03	.2884-15	.3776-07	.2588-04
.26	.235-02	.570-03	.1177 05	.512 01	.9582 02	.2695-01	.7236-02	.3219-03	.1422-16	.8262-08	.1413-04
.24	.183-02	.409-03	.1188 05	.537 01	.1220 03	.2696-01	.7240-02	.3219-03	.4191-18	.1364-08	.6976-05
.22	.140-02	.287-03	.1199 05	.565 01	.1581 03	.2696-01	.7242-02	.3219-03	.6413-20	.1652-09	.3028-05
.20	.105-02	.195-03	.1209 05	.596 01	.2092 03	.2696-01	.7243-02	.3219-03	.4181-22	.1266-10	.1112-05
.18	.767-03	.129-03	.1219 05	.632 01	.2836 03	.2696-01	.7243-02	.3219-0[illegible]	.8735-25	.5372-12	.3270-06
.16	.544-03	.812-04	.1229 05	.674 01	.3962 03	.2696-01	.7244-02	.3219-03	.3811-28	.1010-13	.7085-07
.14	.372-03	.486-04	.1238 05	.724 01	.5749 03	.2696-01	.7244-02	.3219-03	.1772-32	.5926-16	.9932-08
.12	.243-03	.271-04	.1248 05	.786 01	.8756 03	.2696-01	.7244-02	.3219-03		.6039-19	.7254-09
.10	.146-03	.138-04	.1257 05	.864 01	.1424 04	.2696-01	.7244-02	.3219-03		.3725-23	.1870-10
.08	.824-04	.615-05	.1266 05	.969 01	.2542 04	.2696-01	.7244-02	.3219-03		.1683-29	.7815-13
.06	.396-04	.222-05	.1275 05	.112 02	.5250 04	.2696-01	.7244-02	.3219-03			.8645-17
.04	.146-04	.546-06	.1283 05	.138 02	.1411 05	.2696-01	.7244-02	.3219-03			.1111-24
.02	.286-05	.533-07	.1291 05	.195 02	.7185 05	.2696-01	.7244-02	.3219-03			

T[32]	$T_{N_2^+}$	$T_{O_2^+}$	T_{NO^+}	T_{N^+}	T_{O^+}	T_{O^-}	T_{e^-}
1.00	.1213-10	.1672-06	.3254-06	.3277-12	.4026-10	.9540-07	.2317-[illegible]
.98	.7472-11	.1292-08	.2670-06	.1789-12	.2634-10	.7559-07	.1927-[illegible]
.96	.4512-11	.9650-09	.2172-06	.9523-13	.1690-10	.5920-07	.1590-[illegible]
.94	.2669-11	.7412-09	.1750-06	.4934-13	.1063-10	.4579-07	.1300-[illegible]
.92	.1545-11	.5497-09	.1397-06	.2464-13	.6547-11	.3495-07	.1053-[illegible]
.90	.6733-12	.4014-09	.1103-06	.1213-13	.3938-11	.2629-07	[illegible]
.88	.4815-12	.2863-09	.8606-07	.5729-14	.2311-11	.1946-07	[illegible]
.86	.2585-12	.2034-09	.6635-07	.2613-14	.1321-11	[illegible]	[illegible]
.84	.1349-12	.1408-09	.5048-07	.1146-14	.7352-12	[illegible]	[illegible]
.82	.6626-13	.9543-10	.3786-07	.4639-15	.3947-12	.7105-08	[illegible]
.80	.3342-13	.6325-10	.2796-07	.1952-15	.2054-12	.4676-08	[illegible]
.78	.1578-13	.4091-10	.2030-07	.7509-16	.1031-12	[illegible]	[illegible]
.76	.7173-14	.2577-10	.1447-07	.2742-16	.4969-13	.2139-08	[illegible]
.74	.3125-14	.1577-10	.1011-07	.9465-17	.2294-13	[illegible]	[illegible]
.72	.1301-14	.9354-11	.6910-08	.3071-17	.1010-13	[illegible]	[illegible]
.70	.5150-15	.5359-11	.4609-08	.9312-18	.4217-14	.5037-09	[illegible]
.68	.1931-15	.2957-11	.2994-08	.2621-18	.1663-14	.2911-09	[illegible]
.66	.6815-16	.1565-11	.1888-08	.6799-19	.6153-15	.1619-09	.1727-[illegible]
.64	.2252-16	.7913-12	.1152-08	.1611-19	.2122-15	[illegible]	[illegible]
.62	.6916-17	.3804-12	.6782-09	.3456-20	.6771-16	.4405-10	.6346-[illegible]
.60	.1961-17	.1729-12	.3635-09	.6635-21	.1982-16	.2134-10	[illegible]
.58	.5081-16	.7392-13	.2074-09	.1127-21	.5270-17	.9783-11	.1977-[illegible]
.56	.1193-18	.2951-13	.1067-09	.1670-22	.1260-17	.4219-11	[illegible]
.54	.2506-19	.1092-13	.5196-10	.2125-23	.2675-18	.1761-11	[illegible]
.52	.4653-20	.3712-14	.2360-10	.2262-24	.4974-19	[illegible]	.2317-[illegible]
.50	.7523-21	.1146-14	.1017-10	.2026-25	.7976-20	.2166-12	[illegible]
.48	.1041-21	.3197-15	.4025-11	.1453-26	.1064-20	[illegible]	.2957-[illegible]
.46	.1206-22	.7902-16	.1460-11	.6163-28	.1221-21	.1924-13	.1441-[illegible]

Table 5. EQUILIBRIUM AIRFLOW EXPANSION

$T_o' = 5000°K$, $p_o' = 200$ atm., $\rho_o' = 1.317 \times 10^{-2}$ gm/cm^3,
$H_o = 5.436$, $(\rho u)_* = .6729$ at $T = .915$, $\bar{\mu}_o = 27.01$ gm/mole

53 T	ρ	p	u′ (ft/sec)	M	A	T_{N_2}	T_{O_2}	T_A	T_N	T_O	T_{NO}	$T_{N_2^+}$	$T_{O_2^+}$	T_{NO^+}	T_{N^+}	T_{O^+}	T_{O^-}	T_{e^-}
1.00	.100 01	.100 01	.0000 00	.000 00	∞	.2477-01	.2987-02	.3219-03	.5692-04	.4196-02	.4316-02	.9999-11	.1520-06	.2616-06	.2198-12	.2635-10	.9625-07	.1849-06
.98	.901 00	.861 00	.2029 04	.460 00	.1443 01	.2482-01	.3119-02	.3219-03	.4768-04	.4020-02	.4229-02	.6152-11	.1167-06	.2303-06	.1198-12	.1647-10	.7770-07	.1538-06
.96	.809 00	.773 00	.2874 04	.658 00	.1134 01	.2487-01	.3256-02	.3219-03	.3964-04	.3838-02	.4136-02	.3711-11	.6847-09	.1867-06	.6364-13	.1161-10	.6074-07	.1268-06
.94	.724 00	.676 00	.3525 04	.818 00	.1033 01	.2493-01	.3399-02	.3219-03	.3267-04	.3651-02	.4037-02	.2193-11	.6616-09	.1499-06	.3290-13	.7392-11	.4869-07	.1037-06
.92	.646 00	.568 00	.4077 04	.958 00	.1002 01	.2498-01	.3548-02	.3219-03	.2669-04	.3459-02	.3932-02	.1267-11	.4875-09	.1191-06	.1652-13	.4526-11	.3572-07	.8390-07
.90	.574 00	.510 00	.4564 04	.109 01	.1007 01	.2504-01	.3702-02	.3219-03	.2159-04	.3262-02	.3821-02	.7153-12	.3537-09	.9367-07	.8042-14	.2709-11	.2662-07	.6721-07
.88	.508 00	.440 00	.5007 04	.121 01	.1037 01	.2510-01	.3861-02	.3219-03	.1729-04	.3062-02	.3703-02	.3936-12	.2523-09	.7280-07	.3787-14	.1561-11	.1962-07	.5323-07
.86	.448 00	.378 00	.5415 04	.133 01	.1087 01	.2516-01	.4024-02	.3219-03	.1368-04	.2859-02	.3579-02	.2110-12	.1768-09	.5588-07	.1721-14	.6977-12	.1441-07	.4165-07
.84	.394 00	.323 00	.5796 04	.144 01	.1156 01	.2523-01	.4192-02	.3219-03	.1070-04	.2654-02	.3449-02	.1099-12	.1215-09	.4232-07	.7528-15	.4952-12	.1026-07	.3216-07
.82	.344 00	.275 00	.6154 04	.155 01	.1245 01	.2530-01	.4364-02	.3219-03	.8257-05	.2448-02	.3312-02	.5545-13	.6176-10	.3158-07	.3159-15	.2046-12	.7198-08	.2447-07
.80	.300 00	.234 00	.6492 04	.166 01	.1354 01	.2537-01	.4538-02	.3219-03	.6281-05	.2241-02	.3169-02	.2707-13	.5378-10	.2321-07	.1266-15	.1367-12	.4932-08	.1833-07
.78	.261 00	.197 00	.6813 04	.177 01	.1486 01	.2545-01	.4715-02	.3219-03	.4703-05	.2036-02	.3021-02	.1275-13	.3452-10	.1676-07	.4850-16	.6605-13	.3303-08	.1349-07
.76	.225 00	.166 00	.7119 04	.187 01	.1645 01	.2553-01	.4893-02	.3219-03	.3462-05	.1834-02	.2867-02	.5773-14	.2156-10	.1188-07	.1760-16	.3255-13	.2157-08	.9746-08
.74	.194 00	.139 00	.7411 04	.198 01	.1834 01	.2561-01	.5071-02	.3219-03	.2500-05	.1635-02	.2709-02	.2506-14	.1310-10	.8253-08	.6034-17	.1489-13	.1371-08	.6895-08
.72	.167 00	.115 00	.7689 04	.208 01	.2056 01	.2569-01	.5249-02	.3219-03	.1769-05	.1443-02	.2547-02	.1039-14	.7709-11	.5607-08	.1944-17	.6491-14	.6465-09	.4768-08
.70	.143 00	.958-01	.7950 04	.219 01	.2324 01	.2577-01	.5424-02	.3219-03	.1223-05	.1258-02	.2381-02	.4098-15	.4381-11	.3718-08	.5848-18	.2685-14	.5060-09	.3216-08
.68	.122 00	.793-01	.8210 04	.229 01	.2638 01	.2585-01	.5596-02	.3219-03	.8252-06	.1082-02	.2213-02	.1529-15	.2398-11	.2400-08	.1633-18	.1048-14	.2921-09	.2110-08
.66	.104 00	.654-01	.8453 04	.240 01	.3008 01	.2594-01	.5764-02	.3219-03	.5413-06	.9168-03	.2043-02	.5375-16	.1259-11	.1504-08	.4200-19	.3839-15	.1623-09	.1343-08
.64	.862-01	.537-01	.8685 04	.250 01	.3445 01	.2602-01	.5925-02	.3219-03	.3444-06	.7641-03	.1873-02	.1768-16	.6317-12	.9121-09	.9869-20	.1311-15	.6652-10	.8283-09
.62	.746-01	.441-01	.8907 04	.261 01	.3958 01	.2611-01	.6079-02	.3219-03	.2118-06	.6252-03	.1704-02	.5407-17	.3014-12	.5337-09	.2098-20	.4140-16	.4405-10	.4899-09
.60	.634-01	.361-01	.9117 04	.271 01	.4562 01	.2619-01	.6224-02	.3219-03	.1254-06	.5012-03	.1538-02	.1525-17	.1360-12	.3000-09	.3995-21	.1200-16	.2133-10	.2768-09
.58	.537-01	.295-01	.9318 04	.282 01	.5271 01	.2627-01	.6360-02	.3219-03	.7121-07	.3927-03	.1374-02	.3936-18	.5776-13	.1614-09	.6730-22	.3161-17	.9776-11	.1517-09
.56	.455-01	.241-01	.9509 04	.292 01	.6102 01	.2635-01	.6485-02	.3219-03	.3860-07	.3000-03	.1216-02	.9201-19	.2292-13	.8263-10	.9896-23	.7492-18	.4215-11	.7843-10
.54	.385-01	.198-01	.9691 04	.303 01	.7077 01	.2643-01	.6600-02	.3219-03	.1987-07	.2228-03	.1064-02	.1926-19	.6433-14	.4005-10	.1251-23	.1576-18	.1656-11	.3636-10
.52	.325-01	.160-01	.9864 04	.313 01	.8221 01	.2650-01	.6704-02	.3219-03	.9652-08	.1604-03	.9197-03	.3565-20	.2854-14	.1827-10	.1335-24	.2915-19	.6349-12	.1763-10
.50	.275-01	.130-01	.1003 05	.324 01	.9566 01	.2657-01	.6796-02	.3219-03	.4395-08	.1115-03	.7841-03	.5747-21	.6795-15	.7781-11	.1179-25	.4649-20	.2182-12	.7563-11
.48	.232-01	.105-01	.1019 05	.335 01	.1115 02	.2663-01	.6877-02	.3219-03	.1861-08	.7459-04	.6585-03	.7934-22	.2441-15	.3070-11	.8418-27	.6286-21	.6826-13	.3002-11
.46	.196-01	.849-02	.1034 05	.346 01	.1304 02	.2669-01	.6948-02	.3219-03	.7260-09	.4777-04	.5436-03	.9190-23	.6016-16	.1111-11	.4727-28	.7055-22	.1921-13	.1092-11
.44	.165-01	.683-02	.1046 05	.358 01	.1526 02	.2674-01	.7009-02	.3219-03	.2581-09	.2913-04	.4403-03							
.42	.136-01	.546-02	.1062 05	.371 01	.1796 02	.2679-01	.7061-02	.3219-03	.8250-10	.1680-04	.3490-03							
.40	.115-01	.435-02	.1076 05	.384 01	.2125 02	.2683-01	.7104-02	.3219-03	.2336-10	.9094-05	.2699-03							
.38	.960-02	.344-02	.1089 05	.397 01	.2524 02	.2686-01	.7140-02	.3219-03	.5744-11	.4575-05	.2029-03							
.36	.794-02	.269-02	.1102 05	.412 01	.3017 02	.2689-01	.7169-02	.3219-03	.1199-11	.2113-05	.1475-03							
.34	.652-02	.209-02	.1114 05	.426 01	.3632 02	.2691-01	.7191-02	.3219-03	.2063-12	.8834-06	.1032-03							
.32	.531-02	.160-02	.1126 05	.445 01	.4409 02	.2693-01	.7209-02	.3219-03	.2823-13	.3279-06	.6901-04							
.30	.429-02	.121-02	.1138 05	.463 01	.5403 02	.2694-01	.7222-02	.3219-03	.2934-14	.1056-06	.4368-04							
.28	.343-02	.904-03	.1150 05	.483 01	.6693 02	.2695-01	.7231-02	.3219-03	.2184-15	.2858-07	.2588-04							
.26	.271-02	.663-03	.1161 05	.505 01	.8398 02	.2695-01	.7236-02	.3219-03	.1077-16	.6254-08	.1413-04							
.24	.211-02	.476-03	.1172 05	.530 01	.1069 03	.2696-01	.7240-02	.3219-03	.3173-18	.1048-08	.6976-05							
.22	.161-02	.334-03	.1182 05	.557 01	.1385 03	.2696-01	.7242-02	.3219-03	.4854-20	.1250-09	.3028-05							
.20	.121-02	.227-03	.1193 05	.566 01	.1832 03	.2696-01	.7243-02	.3219-03	.3165-22	.9582-11	.1112-05							
.18	.883-03	.150-03	.1203 05	.624 01	.2483 03	.2696-01	.7243-02	.3219-03	.6613-25	.4066-12	.3270-06							
.16	.627-03	.945-04	.1213 05	.666 01	.3469 03	.2696-01	.7244-02	.3219-03	.2885-28	.7647-14	.7085-07							
.14	.429-03	.565-04	.1223 05	.715 01	.5032 03	.2696-01	.7244-02	.3219-03	.1342-32	.4486-16	.9932-08							
.12	.279-03	.316-04	.1232 05	.776 01	.7662 03	.2696-01	.7244-02	.3219-03		.4572-19	.7254-09							
.10	.171-03	.181-04	.1242 05	.854 01	.1246 04	.2696-01	.7244-02	.3219-03		.2820-23	.1870-10							
.08	.949-04	.715-05	.1251 05	.957 01	.2223 04	.2696-01	.7244-02	.3219-03		.1274-29	.7815-13							
.06	.456-04	.258-05	.1259 05	.111 02	.4592 04	.2696-01	.7244-02	.3219-03			.5645-17							
.04	.169-04	.635-06	.1266 05	.136 02	.1234 05	.2696-01	.7244-02	.3219-03			.1111-24							
.02	.329-05	.620-07	.1276 05	.192 02	.6282 05	.2696-01	.7244-02	.3219-03										

Table 6. EQUILIBRIUM AIRFLOW EXPANSION

$T_o' = 5000°K$, $p_o' = 300$ atm., $\rho_o' = 1.995 \times 10^{-2}$ gm/cm^3,

$H_o = 5.313$, $(\rho u)_* = .6697$ at $T = .913$, $\bar{\mu}_o = 27.28$ gm/mole

T^{21}	ρ	P	u' (ft/sec)	M	A	τ_{N_2}	τ_{O_2}	τ_A	τ_N	τ_O	τ_{NO}
1.00	.100 01	.100 01	.0000 00	.000 00	—	.2458-01	.3625-02	.3219-03	.3068-04	.2502-02	.4736-02
.98	.906 00	.886 00	.1958 04	.448 00	.1472 01	.2464-01	.3746-02	.3219-03	.2565-04	.2378-02	.4618-02
.96	.818 00	.763 00	.2771 04	.641 00	.1151 01	.2470-01	.3870-02	.3219-03	.2127-04	.2252-02	.4494-02
.94	.737 00	.689 00	.3397 04	.795 00	.1043 01	.2477-01	.3999-02	.3219-03	.1748-04	.2125-02	.4365-02
.92	.662 00	.609 00	.3925 04	.930 00	.1005 01	.2484-01	.4130-02	.3219-03	.1423-04	.1995-02	.4231-02
.90	.593 00	.529 00	.4391 04	.105 01	.1003 01	.2491-01	.4266-02	.3219-03	.1147-04	.1865-02	.4091-02
.88	.530 00	.461 00	.4813 04	.117 01	.1024 01	.2498-01	.4404-02	.3219-03	.9144-05	.1734-02	.3946-02
.86	.472 00	.400 00	.5201 04	.128 01	.1065 01	.2506-01	.4544-02	.3219-03	.7205-05	.1603-02	.3795-02
.84	.419 00	.346 00	.5561 04	.139 01	.1122 01	.2514-01	.4687-02	.3219-03	.5606-05	.1473-02	.3640-02
.82	.370 00	.299 00	.5899 04	.149 01	.1195 01	.2522-01	.4832-02	.3219-03	.4302-05	.1344-02	.3479-02
.80	.327 00	.237 00	.6219 04	.159 01	.1264 01	.2530-01	.4978-02	.3219-03	.3253-05	.1217-02	.3314-02
.78	.286 00	.220 00	.6521 04	.169 01	.1392 01	.2539-01	.5124-02	.3219-03	.2420-05	.1093-02	.3145-02
.76	.252 00	.186 00	.6808 04	.179 01	.1520 01	.2547-01	.5270-02	.3219-03	.1769-05	.9734-03	.2973-02
.74	.221 00	.159 00	.7063 04	.189 01	.1670 01	.2556-01	.5416-02	.3219-03	.1268-05	.8579-03	.2797-02
.72	.193 00	.135 00	.7344 04	.199 01	.1646 01	.2565-01	.5560-02	.3219-03	.8903-06	.7479-03	.2619-02
.70	.166 00	.114 00	.7594 04	.209 01	.2052 01	.2574-01	.5702-02	.3219-03	.6108-06	.6441-03	.2440-02
.68	.145 00	.962-01	.7834 04	.218 01	.2291 01	.2583-01	.5840-02	.3219-03	.4086-06	.5474-03	.2260-02
.66	.126 00	.807-01	.8063 04	.228 01	.2570 01	.2592-01	.5975-02	.3219-03	.2658-06	.4585-03	.2080-02
.64	.109 00	.676-01	.8263 04	.236 01	.2895 01	.2601-01	.6104-02	.3219-03	.1677-06	.3778-03	.1901-02
.62	.939-01	.564-01	.8494 04	.248 01	.3273 01	.2610-01	.6228-02	.3219-03	.1023-06	.3057-03	.1725-02
.60	.809-01	.470-01	.8696 04	.256 01	.3715 01	.2619-01	.6346-02	.3219-03	.6010-07	.2426-03	.1552-02
.58	.695-01	.390-01	.8890 04	.268 01	.4227 01	.2627-01	.6457-02	.3219-03	.3389-07	.1883-03	.1385-02
.56	.596-01	.323-01	.9076 04	.278 01	.4827 01	.2635-01	.6561-02	.3219-03	.1825-07	.1426-03	.1223-02
.54	.510-01	.266-01	.9255 04	.288 01	.5531 01	.2643-01	.6657-02	.3219-03	.9339-08	.1052-03	.1069-02
.52	.436-01	.219-01	.9426 04	.298 01	.6357 01	.2650-01	.6745-02	.3219-03	.4514-08	.7524-04	.9225-03
.50	.371-01	.179-01	.9592 04	.309 01	.7331 01	.2657-01	.6825-02	.3219-03	.2047-08	.5205-04	.7858-03
.48	.316-01	.146-01	.9751 04	.320 01	.8484 01	.2663-01	.6897-02	.3219-03	.8640-09	.3468-04	.6594-03
.46	.267-01	.119-01	.9906 04	.331 01	.9857 01	.2669-01	.6960-02	.3219-03	.3362-09	.2214-04	.5441-03
.44	.226-01	.958-02	.1005 05	.343 01	.1150 02	.2674-01	.7017-02	.3219-03	.1193-09	.1347-04	.4406-03
.42	.190-01	.769-02	.1020 05	.355 01	.1346 02	.2679-01	.7065-02	.3219-03	.3809-10	.7758-05	.3492-03
.40	.159-01	.613-02	.1034 05	.368 01	.1589 02	.2683-01	.7106-02	.3219-03	.1077-10	.4195-05	.2700-03
.38	.132-01	.465-02	.1047 05	.362 01	.1664 02	.2686-01	.7141-02	.3219-03	.2648-11	.2109-05	.2029-03
.36	.109-01	.380-02	.1061 05	.397 01	.2249 02	.2689-01	.7169-02	.3219-03	.5525-12	.9740-06	.1476-03
.34	.899-02	.295-02	.1074 05	.412 01	.2704 02	.2691-01	.7192-02	.3219-03	.9506-13	.4071-06	.1032-03
.32	.733-02	.226-02	.1086 05	.429 01	.3279 02	.2693-01	.7209-02	.3219-03	.1301-13	.1511-06	.6901-04
.30	.592-02	.171-02	.1098 05	.447 01	.4015 02	.2694-01	.7222-02	.3219-03	.1352-14	.4864-07	.4368-04
.28	.473-02	.128-02	.1110 05	.467 01	.4970 02	.2695-01	.7231-02	.3219-03	.1006-15	.1317-07	.2588-04
.26	.373-02	.937-03	.1122 05	.486 01	.6231 02	.2695-01	.7236-02	.3219-03	.4961-17	.2881-08	.1413-04
.24	.291-02	.673-03	.1133 05	.512 01	.7925 02	.2696-01	.7240-02	.3219-03	.1462-18	.4829-09	.6976-05
.22	.222-02	.472-03	.1144 05	.539 01	.1027 03	.2696-01	.7242-02	.3219-03	.2236-20	.5760-10	.3028-05
.20	.167-02	.321-03	.1155 05	.570 01	.1357 03	.2696-01	.7243-02	.3219-03	.1458-22	.4414-11	.1112-05
.18	.122-02	.212-03	.1166 05	.604 01	.1838 03	.2696-01	.7243-02	.3219-03	.3046-25	.1873-12	.3270-06
.16	.665-03	.134-03	.1176 05	.645 01	.2566 03	.2696-01	.7244-02	.3219-03	.1329-28	.3523-14	.7085-07
.14	.592-03	.799-04	.1166 05	.694 01	.3720 03	.2696-01	.7244-02	.3219-03	.6181-33	.2067-16	.9932-08
.12	.386-03	.446-04	.1196 05	.753 01	.5663 03	.2696-01	.7244-02	.3219-03		.2106-19	.7254-09
.10	.235-03	.227-04	.1205 05	.829 01	.9202 03	.2696-01	.7244-02	.3219-03		.1299-23	.1870-10
.08	.131-03	.101-04	.1215 05	.930 01	.1642 04	.2696-01	.7244-02	.3219-03		.5871-30	.7815-13
.06	.630-04	.364-05	.1224 05	.108 02	.3389 04	.2696-01	.7244-02	.3219-03			.8645-17
.04	.233-04	.898-06	.1232 05	.132 02	.9105 04	.2696-01	.7244-02	.3219-03			.1111-24
.02	.454-05	.876-07	.1241 05	.167 02	.4633 05	.2696-01	.7244-02	.3219-03			

T^{21}	$\tau_{N_2^+}$	$\tau_{O_2^+}$	τ_{NO^+}	τ_{N^+}	τ_{O^+}	τ_{O^-}	τ_{e^-}
1.00	.5974-11	.1111-08	.1861-06	.7136-13	.1016-10	.9727-07	.8996-07
.98	.3659-11	.6398-09	.1507-06	.3861-13	.6549-11	.7672-07	.7460-07
.96	.2196-11	.6266-09	.1209-06	.2035-13	.4129-11	.5982-07	.6167-07
.94	.1291-11	.4610-09	.9599-07	.1042-13	.2548-11	.4607-07	.5039-07
.92	.7415-12	.3340-09	.7543-07	.5184-14	.1537-11	.3501-07	.4076-07
.90	.4159-12	.2382-09	.5661-07	.2497-14	.9652-12	.2625-07	.3262-07
.88	.2273-12	.1669-09	.4499-07	.1182-14	.5192-12	.1935-07	.2580-07
.86	.1209-12	.1148-09	.3409-07	.5214-15	.2896-12	.1404-07	.2016-07
.84	.6241-13	.7746-10	.2547-07	.2249-15	.1567-12	.1001-07	.1554-07
.82	.3122-13	.5114-10	.1874-07	.9299-16	.8210-13	.6998-08	.1180-07
.80	.1510-13	.3299-10	.1357-07	.3673-16	.4152-13	.4790-08	.8815-08
.78	.7036-14	.2076-10	.9656-08	.1381-16	.2022-13	.3200-08	.6471-08
.76	.3152-14	.1272-10	.6740-08	.4922-17	.9450-14	.2095-08	.4860-08
.74	.1353-14	.7567-11	.4608-08	.1655-17	.4223-14	.1330-08	.3266-08
.72	.5544-15	.4362-11	.3081-08	.5226-18	.1797-14	.8213-09	.2264-08
.70	.2159-15	.2430-11	.2010-08	.1540-18	.7255-15	.4912-09	.1521-08
.68	.7960-16	.1304-11	.1276-08	.4212-19	.2763-15	.2838-09	.9938-09
.66	.2762-16	.6712-12	.7871-09	.1061-19	.9874-16	.1578-09	.6299-09
.64	.8973-17	.3304-12	.4700-09	.2440-20	.3290-16	.8424-10	.3881-09
.62	.2710-17	.1546-12	.2706-09	.5083-21	.1015-16	.4298-10	.2260-09
.60	.7556-18	.6673-13	.1501-09	.9488-22	.2878-17	.2064-10	.1293-09
.58	.1926-18	.2873-13	.7965-10	.1569-22	.7427-18	.9569-11	.7011-10
.56	.4460-19	.1124-13	.4029-10	.2268-23	.1727-18	.4134-11	.3616-10
.54	.9246-20	.4085-14	.1932-10	.2625-24	.3576-19	.1670-11	.1785-10
.52	.1697-20	.1367-14	.8725-11	.2973-25	.6513-20	.6255-12	.8181-11
.50	.2717-21	.4176-15	.3686-11	.2596-26	.1026-20	.2155-12	.3471-11
.48	.3728-22	.1150-15	.1444-11	.1836-27	.1373-21	.5756-13	.1377-11

Table 7. EQUILIBRIUM AIRFLOW EXPANSION

$T_o{}' = 5000°K$, $p_o{}' = 1000$ atm., $\rho_o{}' = 6.810 \times 10^{-2}$ gm/cm^3,
$H_o = 5.026$, $(\rho u)_* = .6628$ at $T = .909$, $\bar{\mu}_o = 27.94$ gm/mole

T [12]	ρ	P	u' (ft/sec.)	M	A	γ_{N_2}	γ_{O_2}	γ_A	γ_N
1.00	.100 01	.100 01	.0000 00	.000 00	∞	.2512-01	.6800-03	.3219-03	.7444-03
.98	.908 00	.886 00	.2267 04	.445 00	.1477 01	.2517-01	.7307-03	.3219-03	.6458-03
.96	.820 00	.783 00	.3202 04	.637 00	.1156 01	.2521-01	.7880-03	.3219-03	.5563-03
.94	.741 00	.691 00	.3916 04	.786 00	.1046 01	.2525-01	.8528-03	.3219-03	.4756-03
.92	.667 00	.607 00	.4521 04	.921 00	.1006 01	.2528-01	.9260-03	.3219-03	.4034-03
.90	.600 00	.532 00	.5054 04	.104 01	.1002 01	.2531-01	.1009-02	.3219-03	.3394-03
.88	.537 00	.465 00	.5538 04	.116 01	.1021 01	.2534-01	.1102-02	.3219-03	.2830-03
.86	.479 00	.404 00	.5985 04	.127 01	.1059 01	.2536-01	.1206-02	.3219-03	.2339-03
.84	.425 00	.349 00	.6405 04	.138 01	.1114 01	.2539-01	.1324-02	.3219-03	.1915-03
.82	.376 00	.300 00	.6804 04	.149 01	.1187 01	.2541-01	.1455-02	.3219-03	.1551-03
.80	.330 00	.256 00	.7187 04	.159 01	.1279 01	.2543-01	.1601-02	.3219-03	.1244-03
.78	.288 00	.217 00	.7556 04	.170 01	.1394 01	.2546-01	.1763-02	.3219-03	.9858-04
.76	.250 00	.182 00	.7914 04	.181 01	.1538 01	.2548-01	.1942-02	.3219-03	.7719-04
.74	.215 00	.152 00	.8263 04	.193 01	.1712 01	.2551-01	.2138-02	.3219-03	.5966-04
.72	.183 00	.125 00	.8605 04	.205 01	.1930 01	.2554-01	.2351-02	.3219-03	.4546-04
.70	.154 00	.102 00	.8940 04	.217 01	.2201 01	.2558-01	.2583-02	.3219-03	.3412-04
.68	.129 00	.814-01	.9270 04	.229 01	.2542 01	.2562-01	.2832-02	.3219-03	.2517-04
.66	.106 00	.657-01	.9595 04	.242 01	.2972 01	.2567-01	.3098-02	.3219-03	.1823-04
.64	.870-01	.517-01	.9914 04	.255 01	.3520 01	.2572-01	.3360-02	.3219-03	.1294-04
.62	.705-01	.402-01	.1023 05	.269 01	.4225 01	.2578-01	.3676-02	.3219-03	.8973-05
.60	.581-01	.309-01	.1053 05	.283 01	.5137 01	.2585-01	.3983-02	.3219-03	.6063-05
.58	.445-01	.234-01	.1083 05	.297 01	.6327 01	.2591-01	.4300-02	.3219-03	.3979-05
.56	.346-01	.175-01	.1113 05	.312 01	.7888 01	.2599-01	.4622-02	.3219-03	.2525-05
.54	.268-01	.130-01	.1141 05	.327 01	.9944 01	.2607-01	.4944-02	.3219-03	.1542-05
.52	.205-01	.953-02	.1168 05	.342 01	.1268 02	.2615-01	.5263-02	.3219-03	.9014-06
.50	.157-01	.695-02	.1194 05	.358 01	.1622 02	.2623-01	.5570-02	.3219-03	.5005-06
.48	.119-01	.504-02	.1219 05	.374 01	.2089 02	.2632-01	.5861-02	.3219-03	.2619-06
.46	.906-02	.366-02	.1242 05	.389 01	.2692 02	.2640-01	.6129-02	.3219-03	.1279-06
.44	.694-02	.267-02	.1264 05	.405 01	.3462 02	.2646-01	.6368-02	.3219-03	.5762-07
.42	.534-02	.195-02	.1283 05	.420 01	.4429 02	.2656-01	.6574-02	.3219-03	.2366-07
.40	.415-02	.144-02	.1301 05	.434 01	.5623 02	.2664-01	.6744-02	.3219-03	.8727-08
.38	.325-02	.107-02	.1318 05	.449 01	.7085 02	.2670-01	.6881-02	.3219-03	.2844-08
.36	.257-02	.799-03	.1333 05	.464 01	.8867 02	.2676-01	.6986-02	.3219-03	.8033-09
.34	.204-02	.599-03	.1347 05	.479 01	.1106 03	.2681-01	.7065-02	.3219-03	.1922-09
.32	.162-02	.448-03	.1360 05	.496 01	.1378 03	.2685-01	.7123-02	.3219-03	.3784-10
.30	.128-02	.332-03	.1373 05	.515 01	.1724 03	.2689-01	.7165-02	.3219-03	.5909-11
.28	.101-02	.244-03	.1385 05	.535 01	.2171 03	.2691-01	.7194-02	.3219-03	.6977-12
.26	.786-03	.177-03	.1396 05	.558 01	.2764 03	.2693-01	.7214-02	.3219-03	.5844-13
.24	.605-03	.125-03	.1408 05	.584 01	.3566 03	.2695-01	.7227-02	.3219-03	.3188-14
.22	.457-03	.868-04	.1419 05	.613 01	.4678 03	.2695-01	.7235-02	.3219-03	.1008-15
.20	.339-03	.585-04	.1430 05	.646 01	.6264 03	.2696-01	.7240-02	.3219-03	.1567-17
.18	.245-03	.381-04	.1440 05	.685 01	.8596 03	.2696-01	.7242-02	.3219-03	.9454-20
.16	.172-03	.236-04	.1450 05	.729 01	.1216 04	.2696-01	.7243-02	.3219-03	.1549-22
.14	.118-03	.140-04	.1460 05	.783 01	.1768 04	.2696-01	.7243-02	.3219-03	.3937-26
.12	.747-04	.774-05	.1470 05	.846 01	.2763 04	.2696-01	.7244-02	.3219-03	.6097-31
.10	.450-04	.388-05	.1480 05	.932 01	.4561 04	.2696-01	.7244-02	.3219-03	
.08	.246-04	.170-05	.1489 05	.104 02	.8276 04	.2696-01	.7244-02	.3219-03	
.06	.116-04	.603-06	.1498 05	.121 02	.1740 05	.2696-01	.7244-02	.3219-03	
.04	.423-05	.146-06	.1507 05	.148 02	.4766 05	.2696-01	.7244-02	.3219-03	
.02	.809-06	.140-07	.1515 05	.209 02	.2476 06	.2696-01	.7244-02	.3219-03	

T	γ_O	γ_{NO}	$\gamma_{N_2^+}$	$\gamma_{O_2^+}$	γ_{NO^+}	γ_{N^+}	γ_{O^+}	γ_{O^-}	γ_{e^-}
1.00	.1019-01	.2934-02	.1793-08	.1366-07	.2760-05	.3109-09	.5201-08	.3531-06	.2428-05
.98	.1008-01	.2939-02	.1195-08	.1141-07	.2373-05	.1889-09	.3738-08	.2973-06	.2092-05
.96	.9964-02	.2945-02	.7815-09	.9441-08	.2027-05	.1121-09	.2644-08	.2486-06	.1791-05
.94	.9829-02	.2951-02	.5016-09	.7741-08	.1718-05	.6497-10	.1838-08	.2062-06	.1522-05
.92	.9677-02	.2956-02	.3157-09	.6266-08	.1446-05	.3668-10	.1256-08	.1697-06	.1284-05
.90	.9508-02	.2960-02	.1945-09	.5051-08	.1207-05	.2015-10	.8415-09	.1383-06	.1074-05
.88	.9320-02	.2963-02	.1173-09	.4011-08	.9980-06	.1076-10	.5528-09	.1115-06	.8913-06
.86	.9111-02	.2962-02	.6908-10	.3145-08	.8179-06	.5576-11	.3555-09	.8886-07	.7326-06
.84	.8881-02	.2958-02	.3970-10	.2433-08	.6636-06	.2801-11	.2235-09	.6992-07	.5963-06
.82	.8628-02	.2948-02	.2223-10	.1853-08	.5326-06	.1360-11	.1371-09	.5423-07	[illegible]
.80	.8351-02	.2933-02	.1211-10	.1369-08	.4225-06	.6375-12	.8201-10	.4141-07	.3826-06
.78	.8050-02	.2910-02	.6409-11	.1022-08	.3311-06	.2677-12	.4771-10	.3106-07	.3011-06
.76	.7724-02	.2879-02	.3287-11	.7373-09	.2559-06	.1247-12	.2695-10	.2265-07	.2338-06
.74	.7373-02	.2839-02	.1630-11	.5206-09	.1950-06	.5178-13	.1474-10	.1646-07	.1791-06
.72	.6996-02	.2788-02	.7798-12	.3590-09	.1462-06	.2052-13	.7791-11	.1158-07	.1350-06
.70	.6596-02	.2725-02	.3586-12	.2412-09	.1078-06	.7732-14	.3965-11	.7934-08	.1001-06
.68	.6172-02	.2651-02	.1583-12	.1574-09	.7792-07	.2756-14	.1936-11	.5285-08	.7280-07
.66	.5728-02	.2564-02	.6667-13	.9960-10	.5518-07	.9266-15	.9039-12	.3408-08	.5168-07
.64	.5264-02	.2463-02	.2670-13	.6066-10	.3619-07	.2914-15	.4014-12	.2124-08	.3612-07
.62	.4785-02	.2351-02	.1011-13	.3576-10	.2575-07	.8516-16	.1666-12	.1273-08	.2452-07
.60	.4295-02	.2225-02	.3501-14	.2015-10	.1688-07	.2294-16	.6654-13	.7316-09	.1616-07
.58	.3798-02	.2089-02	.1197-14	.1082-10	.1070-07	.5642-17	.2449-13	.4010-09	.1051-07
.56	.3302-02	.1942-02	.3685-15	.5501-11	.6544-08	.1252-17	.6326-14	.2067-09	.6541-08
.54	.2812-02	.1786-02	.1040-15	.2633-11	.3836-08	.2473-18	.2587-14	.1025-09	.3736-08
.52	.2339-02	.1623-02	.2661-16	.1176-11	.2143-08	.4277-19	.7251-15	.4716-10	.2097-08
.50	.1891-02	.1456-02	.6090-17	.4853-12	.1132-08	.6356-20	.1605-15	.2019-10	.1113-08
.48	.1478-02	.1287-02	.1227-17	.1830-12	.5611-09	.7933-21	.3916-16	.7970-11	.5553-09
.46	.1111-02	.1119-02	.2137-18	.6225-13	.2581-09	.8097-22	.7251-17	.2871-11	.2553-09
.44	.7968-03	.9548-03	.3146-19	.1880-13	.1090-09	.6553-23	.1118-17	.9322-12	.1081-09
.42	.5418-03	.7962-03	.3817-20	.4956-14	.4165-10	.4057-24	.1395-18	.2691-12	.4138-10
.40	.3464-03	.6521-03	.3706-21	.1116-14	.1420-10	.1644-25	.1363-19	.6769-13	.1413-10
.38	.2065-03	.5190-03	.2779-22	.2106-15	.4245-11	.5661-27	.1006-20	.1467-13	.4236-11
.36	.1137-03	.4011-03	.1544-23	.3236-16	.1091-11		.5371-22	.2651-14	.1088-11
.34	.5722-04	.2996-03							
.32	.2595-04	.2152-03							
.30	.1041-04	.1475-03							
.28	.3613-05	.9561-04							
.26	.1046-05	.5788-04							
.24	.2437-06	.3219-04							
.22	.4268-07	.1607-04							
.20	.5177-08	.6976-05							
.18	.3843-09	.2515-05							
.16	.1451-10	.7026-06							
.14	.2080-12	.1364-06							
.12	.6958-15	.1537-07							
.10	.2258-18	.7254-09							
.08	.1226-23	.7499-11							
.06	.1835-32	.3742-14							
.04		.9739-21							
.02									

Table 8. EQUILIBRIUM AIRFLOW EXPANSION

$T_o' = 6000°K$, $p_o' = 100$ atm., $\rho_o' = 5.078 \times 10^{-3}$ gm/cm^3,

$H_o = 6.229$, $(\rho u)_* = .7035$ at $T = .907$, $\overline{\mu}_o = 25.00$ gm/mole

T [13]	ρ	p	u' (ft/sec)	M	A	γ_{N_2}	γ_{O_2}	γ_A	γ_N	γ_O	γ_{NO}	$\gamma_{N_2^+}$	$\gamma_{O_2^+}$	γ_{NO^+}	γ_{N^+}	γ_{O^+}	γ_{O^-}	γ_{e^-}
1.00	.100 01	.100 01	.0000 00	.000 00	∞	.2475-01	.1278-02	.3219-03	.4197-03	.7935-02	.3993-02	.9340-09	.1359-07	.1985-05	.9263-10	.2141-08	.5203-06	.1482-05
.98	.906 00	.866 00	.2212 04	.442 00	.1466 01	.2479-01	.1357-02	.3219-03	.3637-03	.7797-02	.3975-02	.6219-09	.1120-07	.1696-05	.5623-10	.1527-08	.4350-06	.1275-05
.96	.823 00	.786 00	.3130 04	.632 00	.1159 01	.2483-01	.1443-02	.3219-03	.3131-03	.7646-02	.3954-02	.4070-09	.9141-08	.1439-05	.3336-10	.1073-08	.3607-06	.1069-05
.94	.743 00	.693 00	.3837 04	.765 00	.1047 01	.2486-01	.1537-02	.3219-03	.2676-03	.7482-02	.3930-02	.2616-09	.7366-08	.1212-05	.1936-10	.7411-09	.2964-06	.9243-06
.92	.669 00	.609 00	.4436 04	.919 00	.1006 01	.2490-01	.1639-02	.3219-03	.2271-03	.7304-02	.3903-02	.1650-09	.5907-08	.1013-05	.1096-10	.5030-09	.2413-06	.7785-06
.90	.600 00	.533 00	.4966 04	.104 01	.1002 01	.2493-01	.1751-02	.3219-03	.1912-03	.7112-02	.3871-02	.1020-09	.4667-08	.8397-06	.6042-11	.3350-09	.1943-06	.6505-06
.88	.536 00	.464 00	.5449 04	.116 01	.1021 01	.2496-01	.1873-02	.3219-03	.1596-03	.6905-02	.3834-02	.6169-10	.3641-08	.5697-06	.3241-11	.2187-09	.1547-06	.5389-06
.86	.477 00	.402 00	.5896 04	.127 01	.1061 01	.2500-01	.2006-02	.3219-03	.1321-03	.6683-02	.3792-02	.3649-10	.2802-08	.5611-06	.1688-11	.1397-09	.1216-06	.4424-06
.84	.423 00	.347 00	.6316 04	.138 01	.1118 01	.2504-01	.2149-02	.3219-03	.1083-03	.6446-02	.3742-02	.2106-10	.2125-08	.4517-06	.8524-12	.8725-10	.9432-07	.3596-06
.82	.373 00	.297 00	.6714 04	.149 01	.1193 01	.2507-01	.2304-02	.3219-03	.8790-04	.6193-02	.3686-02	.1185-10	.1585-08	.3597-06	.4183-12	.5317-10	.7206-07	.2892-06
.80	.327 00	.253 00	.7094 04	.160 01	.1289 01	.2512-01	.2471-02	.3219-03	.7058-04	.5924-02	.3621-02	.6486-11	.1162-08	.2829-06	.1962-12	.3155-10	.5415-07	.2300-06
.78	.285 00	.214 00	.7459 04	.171 01	.1407 01	.2516-01	.2650-02	.3219-03	.5601-04	.5640-02	.3547-02	.3449-11	.8363-09	.2197-06	.8901-13	.1820-10	.3997-07	.1806-06
.76	.248 00	.180 00	.7811 04	.182 01	.1552 01	.2521-01	.2841-02	.3219-03	.4390-04	.5342-02	.3464-02	.1777-11	.5894-09	.1682-06	.3876-13	.1016-10	.2893-07	.1399-06
.74	.212 00	.150 00	.8152 04	.194 01	.1730 01	.2526-01	.3043-02	.3219-03	.3394-04	.5029-02	.3371-02	.8644-12	.4062-09	.1269-06	.1614-13	.5511-11	.2049-07	.1065-06
.72	.181 00	.124 00	.8484 04	.205 01	.1947 01	.2531-01	.3258-02	.3219-03	.2585-04	.4704-02	.3267-02	.4244-12	.2732-09	.9409-07	.6407-14	.2876-11	.1417-07	.8019-07
.70	.153 00	.102 00	.8808 04	.217 01	.2214 01	.2536-01	.3484-02	.3219-03	.1937-04	.4367-02	.3153-02	.1957-12	.1768-09	.6852-07	.2413-14	.1443-11	.9554-08	.5915-07
.68	.129 00	.828-01	.9121 04	.228 01	.2544 01	.2544-01	.3720-02	.3219-03	.1425-04	.4020-02	.3027-02	.8637-13	.1137-09	.4891-07	.8563-15	.6931-12	.6260-08	.4276-07
.66	.107 00	.666-01	.9427 04	.241 01	.2951 01	.2551-01	.3965-02	.3219-03	.1028-04	.3665-02	.2891-02	.3636-13	.6995-10	.3415-07	.2867-15	.3174-12	.3975-08	.3025-07
.64	.880-01	.531-01	.9725 04	.253 01	.3456 01	.2559-01	.4216-02	.3219-03	.7254-05	.3306-02	.2745-02	.1452-13	.4154-10	.2327-07	.8933-16	.1376-12	.2438-08	.2087-07
.62	.729-01	.420-01	.1001 05	.266 01	.4091 01	.2566-01	.4477-02	.3219-03	.4992-05	.2945-02	.2588-02	.5477-14	.2371-10	.1543-07	.2577-16	.5644-13	.1440-08	.1401-07
.60	.594-01	.330-01	.1030 05	.278 01	.4884 01	.2575-01	.4739-02	.3219-03	.3341-05	.2586-02	.2423-02	.1938-14	.1295-10	.9922-08	.6827-17	.2164-13	.8156-09	.9119-08
.58	.480-01	.257-01	.1057 05	.292 01	.5881 01	.2584-01	.5002-02	.3219-03	.2166-05	.2234-02	.2249-02	.6385-15	.6731-11	.6166-08	.1643-17	.7705-14	.4409-09	.5722-08
.56	.380-01	.196-01	.1083 05	.305 01	.7137 01	.2593-01	.5262-02	.3219-03	.1355-05	.1893-02	.2069-02	.1943-15	.3311-11	.3687-08	.3553-18	.2524-14	.2264-09	.3464-08
.54	.309-01	.152-01	.1106 05	.318 01	.8716 01	.2602-01	.5517-02	.3219-03	.8142-06	.1570-02	.1884-02	.5410-16	.1531-11	.2110-08	.6804-19	.7526-15	.1097-09	.2001-08
.52	.246-01	.116-01	.1132 05	.332 01	.1070 02	.2611-01	.5761-02	.3219-03	.4670-06	.1269-02	.1697-02	.1362-16	.6599-12	.1149-08	.1136-19	.2016-15	.4995-10	.1099-08
.50	.196-01	.867-02	.1155 05	.345 01	.1319 02	.2621-01	.5991-02	.3219-03	.2540-06	.9956-03	.1509-02	.3062-17	.2627-12	.5907-09	.1623-20	.4782-16	.2113-10	.5699-09
.48	.156-01	.673-02	.1177 05	.359 01	.1626 02	.2630-01	.6204-02	.3219-03	.1300-06	.7553-03	.1323-02	.6051-18	.9561-13	.2848-09	.1943-21	.9873-17	.8254-11	.2766-09
.46	.124-01	.513-02	.1197 05	.373 01	.2010 02	.2639-01	.6397-02	.3219-03	.6208-07	.5511-03	.1143-02	.1033-18	.3141-13	.1275-09	.1901-22	.1739-17	.2946-11	.1246-09
.44	.991-02	.391-02	.1216 05	.386 01	.2479 02	.2648-01	.6567-02	.3219-03	.2738-07	.3846-03	.9694-03	.1491-19	.9190-14	.5244-10	.1476-23	.2557-18	.9453-12	.5150-10
.42	.793-02	.296-02	.1234 05	.400 01	.3052 02	.2656-01	.6713-02	.3219-03	.1103-07	.2552-03	.8066-03	.1776-20	.2356-14	.1959-10	.6600-25	.3057-19	.2723-12	.1932-10
.40	.637-02	.228-02	.1250 05	.414 01	.3751 02	.2663-01	.6835-02	.3219-03	.4000-08	.1598-03	.6565-03	.1698-21	.5191-15	.6549-11	.3672-26	.2882-20	.6836-13	.6481-11
.38	.512-02	.174-02	.1266 05	.428 01	.4605 02	.2670-01	.6936-02	.3219-03	.1287-08	.9380-04	.5211-03	.1258-22	.9616-16	.1928-11	.1200-27	.2069-21	.1473-13	.1914-11
.36	.412-02	.133-02	.1280 05	.443 01	.5656 02	.2676-01	.7017-02	.3219-03	.3601-09	.5106-04	.4020-03							
.34	.331-02	.101-02	.1294 05	.459 01	.6963 02	.2681-01	.7081-02	.3219-03	.8561-10	.2552-04	.3000-03							
.32	.265-02	.757-03	.1308 05	.476 01	.8610 02	.2685-01	.7130-02	.3219-03	.1679-10	.1152-04	.2153-03							
.30	.211-02	.564-03	.1320 05	.494 01	.1072 03	.2689-01	.7167-02	.3219-03	.2618-11	.4614-05	.1475-03							
.28	.166-02	.415-03	.1333 05	.515 01	.1347 03	.2691-01	.7195-02	.3219-03	.3088-12	.1599-05	.9562-04							
.26	.130-02	.301-03	.1345 05	.536 01	.1713 03	.2693-01	.7214-02	.3219-03	.2585-13	.4638-06	.5788-04							
.24	.997-03	.213-03	.1357 05	.563 01	.2206 03	.2695-01	.7227-02	.3219-03	.1410-14	.1078-06	.3219-04							
.22	.754-03	.146-03	.1366 05	.592 01	.2894 03	.2695-01	.7236-02	.3219-03	.4459-16	.1888-07	.1607-04							
.20	.559-03	.997-04	.1379 05	.624 01	.3873 03	.2696-01	.7240-02	.3219-03	.6933-18	.2290-08	.6976-05							
.18	.404-03	.649-04	.1390 05	.661 01	.5312 03	.2696-01	.7242-02	.3219-03	.4182-20	.1700-09	.2515-05							
.16	.284-03	.405-04	.1401 05	.705 01	.7513 03	.2696-01	.7243-02	.3219-03	.6851-23	.6416-11	.7026-06							
.14	.192-03	.239-04	.1411 05	.757 01	.1104 04	.2696-01	.7243-02	.3219-03	.1741-26	.9199-13	.1364-06							
.12	.123-03	.132-04	.1421 05	.820 01	.1705 04	.2696-01	.7244-02	.3219-03	.2697-31	.3078-15	.1537-07							
.10	.742-04	.661-05	.1431 05	.902 01	.2613 04	.2696-01	.7244-02	.3219-03		.9989-19	.7254-09							
.08	.406-04	.290-05	.1441 05	.101 02	.5103 04	.2696-01	.7244-02	.3219-03		.5423-24	.7499-11							
.06	.192-04	.103-05	.1450 05	.117 02	.1072 05	.2696-01	.7244-02	.3219-03		.8116-33	.3742-14							
.04	.697-05	.249-06	.1459 05	.143 02	.2936 05	.2696-01	.7244-02	.3219-03			.9739-21							
.02	.133-05	.238-07	.1468 05	.202 02	.1525 06	.2696-01	.7244-02	.3219-03										

Table 9. **EQUILIBRIUM AIRFLOW EXPANSION**

$T_o' = 6000°K$, $p_o' = 300$ atm., $\rho_o' = 1.574 \times 10^{-2}$ gm/cm^3,

$H_o = 5.850$, $(\rho u)_* = .6920$ at $T = .907$, $\overline{\mu}_o = 25.84$ gm/mole

T [14]	ρ	P	u' (ft/sec)	M	A	τ_{N_2}	τ_{O_2}	τ_A	τ_N	τ_O	τ_{NO}	$\tau_{N_2^+}$	$\tau_{O_2^+}$	τ_{NO^+}	τ_{N^+}	τ_{O^+}	τ_{O^-}	τ_{e^-}
1.00	.100 01	.100 01	.0000 00	.000 00	∞	.2435-01	.2042-02	.3219-03	.2239-03	.5396-02	.5005-02	.5126-09	.1212-07	.1369-05	.2756-10	.8123-09	.6339-06	.7663-06
.98	.909 00	.869 00	.2157 04	.439 00	.1495 01	.2439-01	.2138-02	.3219-03	.1939-03	.5261-02	.4949-02	.3409-09	.9632-08	.1177-05	.1671-10	.5744-09	.5267-06	.6609-06
.96	.825 00	.766 00	.3054 04	.626 00	.1164 01	.2443-01	.2240-02	.3219-03	.1669-03	.5116-02	.4888-02	.2229-09	.7899-08	.9901-06	.9902-11	.3997-09	.4336-06	.5649-06
.94	.746 00	.696 00	.3746 04	.760 00	.1050 01	.2446-01	.2349-02	.3219-03	.1426-03	.4967-02	.4822-02	.1432-09	.6277-08	.8267-06	.5735-11	.2735-09	.3540-06	.4794-06
.92	.672 00	.613 00	.4331 04	.913 00	.1007 01	.2453-01	.2465-02	.3219-03	.1210-03	.4806-02	.4750-02	.9024-10	.4930-08	.6846-06	.3241-11	.1838-09	.2860-06	.4026-06
.90	.604 00	.537 00	.4850 04	.104 01	.1001 01	.2457-01	.2588-02	.3219-03	.1018-03	.4637-02	.4672-02	.5574-10	.3824-08	.5620-06	.1784-11	.1211-09	.2285-06	.3372-06
.88	.540 00	.469 00	.5321 04	.115 01	.1020 01	.2462-01	.2720-02	.3219-03	.8497-04	.4459-02	.4588-02	.3369-10	.2927-08	.4570-06	.9552-12	.7619-10	.1804-06	.2796-06
.86	.482 00	.407 00	.5757 04	.126 01	.1057 01	.2466-01	.2859-02	.3219-03	.7028-04	.4272-02	.4497-02	.1991-10	.2208-08	.3679-06	.4965-12	.4937-10	.1407-06	.2295-06
.84	.426 00	.352 00	.6165 04	.137 01	.1112 01	.2473-01	.3006-02	.3219-03	.5758-04	.4077-02	.4399-02	.1145-10	.1639-08	.2929-06	.2500-12	.3045-10	.1081-06	.1865-06
.82	.376 00	.303 00	.6550 04	.148 01	.1184 01	.2479-01	.3161-02	.3219-03	.4668-04	.3873-02	.4292-02	.6450-11	.1197-08	.2305-06	.1217-12	.1830-10	.8186-07	.1499-06
.80	.333 00	.259 00	.6916 04	.159 01	.1274 01	.2485-01	.3324-02	.3219-03	.3742-04	.3662-02	.4177-02	.3524-11	.8563-09	.1792-06	.5709-13	.1070-10	.6099-07	.1193-06
.78	.291 00	.221 00	.7267 04	.169 01	.1385 01	.2492-01	.3495-02	.3219-03	.2963-04	.3444-02	.4054-02	.1666-11	.6032-09	.1373-06	.2575-13	.6076-11	.4462-07	.9393-07
.76	.254 00	.187 00	.7603 04	.180 01	.1519 01	.2499-01	.3673-02	.3219-03	.2316-04	.3219-02	.3922-02	.9590-12	.4151-09	.1047-06	.1113-13	.3343-11	.3201-07	.7314-07
.74	.220 00	.157 00	.7927 04	.190 01	.1661 01	.2506-01	.3859-02	.3219-03	.1784-04	.2989-02	.3781-02	.4754-12	.2790-09	.7709-07	.4597-14	.1774-11	.2247-07	[illegible]
.72	.192 00	.131 00	.8240 04	.201 01	.1876 01	.2514-01	.4051-02	.3219-03	.1353-04	.2755-02	.3630-02	.2269-12	.1829-09	.5630-07	.1806-14	.9070-12	.1541-07	[illegible]
.70	.165 00	.109 00	.8542 04	.212 01	.2111 01	.2522-01	.4249-02	.3219-03	.1008-04	.2518-02	.3471-02	.1040-12	.1166-09	.4033-07	.6715-15	.4445-12	.1030-07	[illegible]
.68	.139 00	.901-01	.8834 04	.223 01	.2394 01	.2531-01	.4452-02	.3219-03	.7369-05	.2280-02	.3303-02	.4555-13	.7213-10	.2830-07	.2355-15	.2084-12	.6695-08	[illegible]
.66	.118 00	.739-01	.9117 04	.234 01	.2736 01	.2540-01	.4659-02	.3219-03	.5273-05	.2042-02	.3127-02	.1901-13	.4316-10	.1940-07	.7725-16	.9288-13	[illegible]	[illegible]
.64	.993-01	.603-01	.9391 04	.246 01	.3150 01	.2549-01	.4868-02	.3219-03	.3686-05	.1808-02	.2943-02	.7516-14	.2490-10	.1296-07	.2555-16	.3918-13	.2560-08	[illegible]
.62	.822-01	.488-01	.9656 04	.257 01	.3651 01	.2558-01	.5078-02	.3219-03	.2510-05	.1579-02	.2752-02	.2801-14	.1360-10	.8417-08	.6850-17	.1555-13	.1502-08	.5920-08
.60	.694-01	.393-01	.9911 04	.269 01	.4260 01	.2568-01	.5287-02	.3219-03	.1660-05	.1359-02	.2556-02	.9782-15	.7310-11	.5297-08	.1717-17	.5754-14	.8465-09	.4456-08
.58	.577-01	.315-01	.1016 05	.280 01	.5000 01	.2578-01	.5492-02	.3219-03	.1062-05	.1149-02	.2354-02	.3177-15	.3685-11	.3219-08	.4017-18	.1976-14	.4546-09	.2766-08
.56	.476-01	.251-01	.1039 05	.293 01	.5899 01	.2589-01	.5692-02	.3219-03	.6548-06	.9520-03	.2150-02	.9521-16	.1756-11	.1880-08	.8425-19	.6229-15	.2319-09	.1656-08
.54	.395-01	.199-01	.1062 05	.304 01	.6993 01	.2599-01	.5885-02	.3219-03	.3873-06	.7716-03	.1945-02	.2607-16	.7880-12	.1051-08	.1562-19	.1765-15	.1118-09	.9397-09
.52	.324-01	.156-01	.1084 05	.316 01	.8322 01	.2609-01	.6068-02	.3219-03	.2186-06	.6097-03	.1741-02	.6454-17	.3298-12	.5567-09	.2521-20	.4591-16	.5028-10	.5064-09
.50	.267-01	.122-01	.1104 05	.329 01	.9934 01	.2619-01	.6240-02	.3219-03	.1170-06	.4681-03	.1540-02	.1426-17	.1275-12	.2806-09	.3485-21	.1046-16	.2132-10	.2598-09
.48	.219-01	.975-02	.1124 05	.341 01	.1189 02	.2629-01	.6398-02	.3219-03	.5894-07	.3478-03	.1344-02	.2770-18	.4516-13	.1324-09	.4035-22	.2082-17	.8496-11	.1242-09
.46	.180-01	.788-02	.1143 05	.353 01	.1426 02	.2638-01	.6541-02	.3219-03	.2773-07	.2490-03	.1155-02	.4653-19	.1446-13	.5810-10	.3627-23	.3542-18	.2922-11	.5516-10
.44	.147-01	.601-02	.1161 05	.366 01	.1714 02	.2647-01	.6670-02	.3219-03	.1207-07	.1709-03	.9769-03	.6622-20	.4147-14	.2348-10	.2891-24	.5049-19	.9494-12	.2254-10
.42	.121-01	.459-02	.1177 05	.379 01	.2063 02	.2656-01	.6782-02	.3219-03	.4808-08	.1118-03	.8107-03	.7795-21	.1045-14	.8640-11	.1684-25	.5880-20	.2728-12	.8269-11
.40	.980-02	.361-02	.1194 05	.393 01	.2491 02	.2663-01	.6880-02	.3219-03	.1729-08	.6931-04	.6586-03	.7377-22	.2270-15	.2655-11	.7272-27	.5431-21	.6624-13	.2767-11
.38	.804-02	.283-02	.1209 05	.407 01	.3016 02	.2670-01	.6962-02	.3219-03	.5525-09	.4035-04	.5221-03	.5422-23	.4162-16	.8331-12	.2222-28	.3637-22	.1470-13	.8164-12
.36	.653-02	.217-02	.1224 05	.422 01	.3669 02	.2676-01	.7031-02	.3219-03	.1539-09	.2186-04	.4024-03							
.34	.526-02	.166-02	.1238 05	.438 01	.4487 02	.2681-01	.7088-02	.3219-03	.3649-10	.1088-04	.3001-03							
.32	.424-02	.125-02	.1252 05	.455 01	.5525 02	.2685-01	.7133-02	.3219-03	.7145-11	.4903-05	.2153-03							
.30	.336-02	.937-03	.1265 05	.473 01	.6861 02	.2689-01	.7169-02	.3219-03	.1113-11	.1962-05	.1475-03							
.28	.267-02	.690-03	.1278 05	.494 01	.8607 02	.2691-01	.7195-02	.3219-03	.1312-12	.6794-06	.9562-04							
.26	.208-02	.500-03	.1291 05	.516 01	.1093 03	.2693-01	.7215-02	.3219-03	.1098-13	.1970-06	.5788-04							
.24	.160-02	.355-03	.1303 05	.541 01	.1406 03	.2695-01	.7227-02	.3219-03	.9991-15	.4578-07	.3219-04							
.22	.121-02	.246-03	.1315 05	.568 01	.1844 03	.2695-01	.7236-02	.3219-03	.1894-16	.8020-08	.1607-04							
.20	.896-03	.166-03	.1326 05	.600 01	.2466 03	.2696-01	.7240-02	.3219-03	.2945-18	.9727-09	.6976-05							
.18	.646-03	.108-03	.1336 05	.636 01	.3381 03	.2696-01	.7242-02	.3219-03	.1776-20	.7221-10	.2515-05							
.16	.455-03	.675-04	.1349 05	.676 01	.4776 03	.2696-01	.7243-02	.3219-03	.2910-23	.2726-11	.7026-06							
.14	.307-03	.398-04	.1360 05	.729 01	.7017 03	.2696-01	.7243-02	.3219-03	.7397-27	.3908-13	.1364-06							
.12	.196-03	.219-04	.1370 05	.791 01	.1083 04	.2696-01	.7244-02	.3219-03	.1146-31	.1307-15	.1537-07							
.10	.119-03	.110-04	.1380 05	.869 01	.1786 04	.2696-01	.7244-02	.3219-03		.4243-19	.7254-09							
.08	.651-04	.462-05	.1390 05	.975 01	.3236 04	.2696-01	.7244-02	.3219-03		.2304-24	.7499-11							
.06	.306-04	.171-05	.1400 05	.113 02	.6801 04	.2696-01	.7244-02	.3219-03		.3448-33	.3742-14							
.04	.112-04	.413-06	.1409 05	.138 02	.1662 05	.2696-01	.7244-02	.3219-03			.9739-21							
.02	.214-05	.396-07	.1418 05	.195 02	.9664 05	.2696-01	.7244-02	.3219-03										

Table 10. EQUILIBRIUM AIRFLOW EXPANSION

$T_o' = 6000°K$, $p_o' = 1000$ atm., $\rho_o' = 5.440 \times 10^{-2}$ gm/cm^3,

$H_o = 5.466$, $(\rho u)_* = .6796$ at $T = .906$, $\overline{\mu}_o = 26.78$ gm/mole

22 T	ρ	P	u' (ft/sec.)	M	A	τ_{N_2}	τ_{O_2}	τ_A	τ_N	τ_O	τ_{NO}	$\tau_{N_2^+}$	$\tau_{O_2^+}$	τ_{NO^+}	τ_{N^+}	τ_{O^+}	τ_{O^-}	τ_{e^-}
1.00	.100 01	.100 01	.0000 00	.000 00	—	.2438-01	.2050-03	.3219-03	.3133-02	.1204-01	.2025-02	.5459-07	.4299-07	.1011-04	.2801-07	.1027-06	.7273-06	.9612-05
.98	.867 00	.866 00	.2735 04	.491 00	.1374 01	.2454-01	.2137-03	.3219-03	.2827-02	.1204-01	.2013-02	.3952-07	.3693-07	.8973-05	.1906-07	.7966-07	.6184-06	.8530-05
.96	.787 00	.750 00	.3652 04	.701 00	.1100 01	.2469-01	.2239-03	.3219-03	.2534-02	.1203-01	.2004-02	.2614-07	.3154-07	.7918-05	.1275-07	.6124-07	.5237-06	.7526-05
.94	.697 00	.646 00	.4697 04	.864 00	.1016 01	.2483-01	.2359-03	.3219-03	.2256-02	.1201-01	.1997-02	.1987-07	.2677-07	.6946-05	.8293-08	.4625-07	.4416-06	.6605-05
.92	.616 00	.560 00	.5399 04	.100 01	.1000 01	.2496-01	.2502-03	.3219-03	.1993-02	.1199-01	.1994-02	.1350-07	.2257-07	.6053-05	.5272-08	.3437-07	.3707-06	.5756-05
.90	.547 00	.484 00	.6009 04	.113 01	.1015 01	.2509-01	.2671-03	.3219-03	.1747-02	.1195-01	.1994-02	.9070-08	.1890-07	.5239-05	.3263-08	.2511-07	.3096-06	.4986-05
.88	.464 00	.417 00	.6551 04	.125 01	.1052 01	.2520-01	.2872-03	.3219-03	.1517-02	.1191-01	.1997-02	.5964-08	.1570-07	.4500-05	.1964-08	.1800-07	.2573-06	.4284-05
.86	.428 00	.360 00	.7041 04	.136 01	.1106 01	.2530-01	.3112-03	.3219-03	.1305-02	.1186-01	.2003-02	.3831-08	.1294-07	.3834-05	.1146-08	.1265-07	.2126-06	.3652-05
.84	.379 00	.310 00	.7490 04	.146 01	.1175 01	.2540-01	.3399-03	.3219-03	.1112-02	.1179-01	.2014-02	.2401-08	.1057-07	.3239-05	.6480-09	.8705-08	.1745-06	.3088-05
.82	.335 00	.257 00	.7906 04	.156 01	.1259 01	.2546-01	.3743-03	.3219-03	.9373-03	.1171-01	.2028-02	.1466-08	.8554-08	.2710-05	.3539-09	.5855-08	.1422-06	.2584-05
.80	.296 00	.225 00	.8293 04	.166 01	.1356 01	.2555-01	.4157-03	.3219-03	.7809-03	.1161-01	.2045-02	.8699-09	.6847-08	.2245-05	.1863-09	.3845-08	.1150-06	.2142-05
.78	.261 00	.196 00	.8655 04	.175 01	.1474 01	.2561-01	.4654-03	.3219-03	.6428-03	.1149-01	.2068-02	.5012-09	.5416-08	.1640-05	.9434-10	.2456-08	.9215-07	.1756-05
.76	.230 00	.166 00	.9004 04	.185 01	.1609 01	.2565-01	.5254-03	.3219-03	.5224-03	.1135-01	.2089-02	.2796-09	.4229-08	.1490-05	.4585-10	.1529-08	.7300-07	.1423-05
.74	.202 00	.143 00	.9334 04	.194 01	.1767 01	.2569-01	.5977-03	.3219-03	.4189-03	.1118-01	.2115-02	.1511-09	.3254-08	.1192-05	.2134-10	.9237-09	.5719-07	.1139-05
.72	.177 00	.122 00	.9652 04	.204 01	.1952 01	.2572-01	.6647-03	.3219-03	.3312-03	.1098-01	.2141-02	.7876-10	.2463-08	.9405-06	.9486-11	.5406-09	.4414-07	.8994-06
.70	.154 00	.103 00	.9962 04	.214 01	.2172 01	.2575-01	.7892-03	.3219-03	.2580-03	.1074-01	.2167-02	.3956-10	.1831-08	.7314-06	.4016-11	.3060-09	.3350-07	.7001-06
.68	.133 00	.856-01	.1027 05	.225 01	.2436 01	.2577-01	.9142-03	.3219-03	.1978-03	.1047-01	.2190-02	.1910-10	.1332-08	.5599-06	.1617-11	.1671-09	.2493-07	.5365-06
.66	.114 00	.711-01	.1057 05	.236 01	.2756 01	.2576-01	.1063-02	.3219-03	.1492-03	.1015-01	.2208-02	.8640-11	.9474-09	.4214-06	.6164-12	.8777-10	.1614-07	.4043-06
.64	.972-01	.583-01	.1087 05	.247 01	.3156 01	.2580-01	.1238-02	.3219-03	.1106-03	.9791-02	.2220-02	.3913-11	.6560-09	.3113-06	.2216-12	.4424-10	.1265-07	.2991-06
.62	.816-01	.471-01	.1117 05	.260 01	.3662 01	.2581-01	.1443-02	.3219-03	.8052-04	.9379-02	.2221-02	.1651-11	.4405-09	.2255-06	.7507-13	.2132-10	.8840-08	.2169-06
.60	.675-01	.375-01	.1147 05	.273 01	.4309 01	.2583-01	.1681-02	.3219-03	.5744-04	.8916-02	.2209-02	.6615-12	.2865-09	.1595-06	.2377-13	.9786-11	.5674-08	.1539-06
.58	.549-01	.293-01	.1177 05	.287 01	.5157 01	.2585-01	.1952-02	.3219-03	.4010-04	.8400-02	.2182-02	.2505-12	.1795-09	.1101-06	.7003-14	.4257-11	.3755-08	.1066-06
.56	.439-01	.224-01	.1206 05	.301 01	.6286 01	.2586-01	.2258-02	.3219-03	.2733-04	.7833-02	.2138-02	.8916-13	.1075-09	.7400-07	.1905-14	.1745-11	.2294-08	.7181-07
.54	.344-01	.166-01	.1239 05	.317 01	.7824 01	.2592-01	.2599-02	.3219-03	.1813-04	.7215-02	.2074-02	.2963-13	.6149-10	.4821-07	.4746-15	.6892-12	.1334-08	.4694-07
.52	.264-01	.123-01	.1271 05	.334 01	.9950 01	.2596-01	.2972-02	.3219-03	.1167-04	.6553-02	.1991-02	.9123-14	.3331-10	.3033-07	.1071-15	.2361-12	.7335-09	.2965-07
.50	.198-01	.880-02	.1302 05	.352 01	.1294 02	.2601-01	.3374-02	.3219-03	.7252-05	.5652-02	.1887-02	.2575-14	.1697-10	.1834-07	.2158-16	.7778-13	.3762-09	.1796-07
.48	.145-01	.613-02	.1333 05	.370 01	.1724 02	.2606-01	.3800-02	.3219-03	.4328-05	.5123-02	.1764-02	.6588-15	.8061-11	.1059-07	.3624-17	.2302-13	.1617-09	.1042-07
.46	.104-01	.416-02	.1364 05	.390 01	.2347 02	.2615-01	.4244-02	.3219-03	.2463-05	.4376-02	.1623-02	.1505-15	.3533-11	.5796-08	.5635-18	.6076-14	.6056-10	.5721-08
.44	.733-02	.276-02	.1395 05	.410 01	.3265 02	.2623-01	.4695-02	.3219-03	.1324-05	.3628-02	.1468-02	.3015-16	.1411-11	.2979-08	.7475-19	.1401-14	.3260-10	.2946-08
.42	.507-02	.182-02	.1424 05	.431 01	.4620 02	.2631-01	.5143-02	.3219-03	.6646-06	.2899-02	.1301-02	.5182-17	.5050-12	.1420-08	.7791-20	.2750-15	.1169-10	.1409-08
.40	.347-02	.117-02	.1452 05	.452 01	.6616 02	.2640-01	.5574-02	.3219-03	.3072-06	.2211-02	.1128-02	.7433-18	.1569-12	.6183-09	.6351-21	.4454-16	.3652-11	.6147-09
.38	.237-02	.756-03	.1476 05	.474 01	.9513 02	.2646-01	.5971-02	.3219-03	.1284-06	.1591-02	.9537-03	.8606-19	.4287-13	.2414-09	.3657-22	.5717-17	.1067-11	.2403-09
.36	.163-02	.469-03	.1502 05	.495 01	.1360 03	.2657-01	.6320-02	.3219-03	.4744-07	.1065-02	.7828-03	.7717-20	.9630-14	.8255-10	.1644-23	.5540-18	.2017-12	.8229-10
.34	.114-02	.322-03	.1523 05	.515 01	.1916 03	.2665-01	.6607-02	.3219-03	.1511-07	.6526-03	.6214-03	.3096-21	.1740-14	.2407-10	.4560-25	.3826-19	.5229-13	.2402-10
.32	.819-03	.218-03	.1542 05	.535 01	.2640 03	.2672-01	.6826-02	.3219-03	.4027-08	.3601-03	.4748-03	.2338-22	.2426-15	.5806-11	.7670-27	.1765-20	.6395-14	.5796-11
.30	.602-03	.146-03	.1558 05	.554 01	.3558 03	.2679-01	.6982-02	.3219-03	.8684-09	.1758-03	.3471-03	.6926-24	.2498-16	.1116-11		.5040-22	.1035-14	.1117-11
.28	.450-03	.103-03	.1573 05	.573 01	.4713 03	.2684-01	.7086-02	.3219-03	.1456-09	.7463-04	.2411-03							
.26	.339-03	.743-04	.1566 05	.594 01	.6197 03	.2688-01	.7151-02	.3219-03	.1802-10	.2689-04	.1576-03							
.24	.256-03	.503-04	.1598 05	.619 01	.8167 03	.2691-01	.7192-02	.3219-03	.1537-11	.7959-05	.9560-04							
.22	.190-03	.343-04	.1610 05	.646 01	.1066 04	.2693-01	.7216-02	.3219-03	.8198-13	.1844-05	.5283-04							
.20	.139-03	.228-04	.1621 05	.662 01	.1476 04	.2695-01	.7230-02	.3219-03	.2379-14	.3114-06	.2588-04							
.18	.997-04	.147-04	.1633 05	.722 01	.2049 04	.2696-01	.7238-02	.3219-03	.3069-16	.3456-07	.1080-04							
.16	.692-04	.937-05	.1643 05	.768 01	.2934 04	.2696-01	.7242-02	.3219-03	.1297-18	.2151-08	.3621-05							
.14	.462-04	.530-05	.1654 05	.824 01	.4365 04	.2696-01	.7243-02	.3219-03	.1112-21	.5853-10	.8880-06							
.12	.293-04	.269-05	.1664 05	.892 01	.6829 04	.2696-01	.7243-02	.3219-03	.8685-26	.4588-12	.1364-06							
.10	.174-04	.143-05	.1674 05	.960 01	.1143 05	.2696-01	.7244-02	.3219-03	.1462-31	.4888-15	.9932-08							
.08	.941-05	.617-06	.1684 05	.110 02	.2106 05	.2696-01	.7244-02	.3219-03		.1571-19	.1963-09							
.06	.438-05	.215-06	.1693 05	.127 02	.4499 05	.2696-01	.7244-02	.3219-03		.4527-27	.2877-12							
.04	.156-05	.512-07	.1702 05	.155 02	.1255 06	.2696-01	.7244-02	.3219-03			.6427-18							

Table 11. EQUILIBRIUM AIRFLOW EXPANSION

$T_o' = 7000°K$, $p_o' = 100$ atm., $\rho_o' = 4.133 \times 10^{-3}$ gm/cm^3,

$H_o = 6.805$, $(\rho u)_* = .7156$ at $T = .920$, $\bar{\mu}_o = 23.74$ gm/mole

T	ρ	p	u' (ft/sec)	M	A	T_{N_2}	T_{O_2}	T_A	T_N	T_O	T_{NO}	$T_{N_2^+}$	$T_{O_2^+}$	T_{NO^+}	T_{N^+}	T_{O^+}	T_{O^-}	T_{e^-}
1.00	.100 01	.100 01	.0000 00	.000 00	∞	.2452-01	.4778-03	.3219-03	.1782-02	.1042-01	.3100-02	.2670-07	.4870-07	.7526-05	.7745-08	.4324-07	.1295-05	.6357-05
.98	.902 00	.861 00	.2522 04	.456 00	.1450 01	.2462-01	.5024-03	.3219-03	.1593-02	.1038-01	.3092-02	.1906-07	.4175-07	.6625-05	.5169-08	.3312-07	.1110-05	.5614-05
.96	.812 00	.776 00	.3557 04	.652 00	.1141 01	.2471-01	.5306-03	.3219-03	.1415-02	.1033-01	.3086-02	.1339-07	.3555-07	.5799-05	.3379-08	.2502-07	.9462-06	.4930-05
.94	.731 00	.681 00	.4344 04	.805 00	.1039 01	.2479-01	.5627-03	.3219-03	.1248-02	.1027-01	.3083-02	.9248-08	.3006-07	.5046-05	.2161-08	.1862-07	.8024-06	.4304-05
.92	.657 00	.598 00	.5002 04	.936 00	.1004 01	.2487-01	.5994-03	.3219-03	.1094-02	.1020-01	.3081-02	.6271-08	.2523-07	.4363-05	.1350-08	.1365-07	.6764-06	.3733-05
.90	.589 00	.523 00	.5576 04	.106 01	.1003 01	.2494-01	.6415-03	.3219-03	.9512-03	.1012-01	.3081-02	.4172-08	.2100-07	.3746-05	.8223-09	.9832-08	.5665-06	.3215-05
.88	.528 00	.457 00	.6095 04	.117 01	.1025 01	.2501-01	.6897-03	.3219-03	.8205-03	.1002-01	.3082-02	.2719-08	.1733-07	.3192-05	.4680-09	.6959-08	.4711-06	.2746-05
.86	.472 00	.398 00	.6567 04	.126 01	.1063 01	.2507-01	.7451-03	.3219-03	.7017-03	.9909-02	.3085-02	.1734-08	.1416-07	.2699-05	.2816-09	.4832-08	.3887-06	.2331-05
.84	.422 00	.346 00	.7006 04	.136 01	.1117 01	.2512-01	.8086-03	.3219-03	.5947-03	.9778-02	.3089-02	.1081-08	.1145-07	.2262-05	.1578-09	.3287-08	.3179-06	.1960-05
.82	.375 00	.300 00	.7416 04	.146 01	.1185 01	.2516-01	.8815-03	.3219-03	.4992-03	.9629-02	.3092-02	.6579-09	.9155-08	.1878-05	.8566-10	.2169-08	.2574-06	.1633-05
.80	.333 00	.259 00	.7805 04	.158 01	.1269 01	.2521-01	.9651-03	.3219-03	.4148-03	.9460-02	.3095-02	.3901-09	.7227-08	.1545-05	.4496-10	.1424-08	.2062-06	.1347-05
.78	.294 00	.222 00	.8175 04	.168 01	.1370 01	.2524-01	.1061-02	.3219-03	.3410-03	.9267-02	.3097-02	.2251-09	.5625-08	.1256-05	.2260-10	.9035-09	.1631-06	.1100-05
.76	.259 00	.190 00	.8532 04	.176 01	.1492 01	.2527-01	.1170-02	.3219-03	.2772-03	.9050-02	.3095-02	.1262-09	.4312-08	.1010-05	.1113-10	.5564-09	.1273-06	.8881-06
.74	.227 00	.161 00	.8870 04	.188 01	.1637 01	.2530-01	.1295-02	.3219-03	.2225-03	.8806-02	.3090-02	.6857-10	.3250-08	.8023-06	.5224-11	.3354-09	.9779-07	.7082-06
.72	.198 00	.136 00	.9211 04	.199 01	.1812 01	.2533-01	.1437-02	.3219-03	.1764-03	.8535-02	.3078-02	.3606-10	.2403-08	.6266-06	.2349-11	.1955-09	.7382-07	.5574-06
.70	.171 00	.114 00	.9540 04	.209 01	.2025 01	.2536-01	.1597-02	.3219-03	.1380-03	.8233-02	.3059-02	.1831-10	.1741-08	.4653-06	.1010-11	.1102-09	.5464-07	.4325-06
.68	.146 00	.944-01	.9863 04	.220 01	.2284 01	.2539-01	.1777-02	.3219-03	.1063-03	.7901-02	.3031-02	.8951-11	.1232-08	.3687-06	.4132-12	.5996-10	.3955-07	.3304-06
.66	.124 00	.774-01	.1016 05	.232 01	.2605 01	.2542-01	.1979-02	.3219-03	.8062-04	.7536-02	.2992-02	.4202-11	.8503-09	.2752-06	.1605-12	.3140-10	.2793-07	.2462-06
.64	.105 00	.628-01	.1050 05	.244 01	.3004 01	.2546-01	.2203-02	.3219-03	.6010-04	.7140-02	.2941-02	.1887-11	.5703-09	.2016-06	.5888-13	.1577-10	.1918-07	.1830-06
.62	.869-01	.503-01	.1081 05	.257 01	.3510 01	.2550-01	.2450-02	.3219-03	.4397-04	.6712-02	.2876-02	.8081-12	.3707-09	.1445-06	.2031-13	.7559-11	.1277-07	.1321-06
.60	.714-01	.397-01	.1112 05	.270 01	.4155 01	.2555-01	.2719-02	.3219-03	.3150-04	.6254-02	.2795-02	.3283-12	.2326-09	.1012-06	.6542-14	.3444-11	.8210-08	.9326-07
.58	.578-01	.309-01	.1143 05	.284 01	.4991 01	.2560-01	.3011-02	.3219-03	.2206-04	.5767-02	.2697-02	.1259-12	.1404-09	.6909-07	.1955-14	.1463-11	.5076-08	.6415-07
.56	.462-01	.236-01	.1174 05	.298 01	.6086 01	.2566-01	.3324-02	.3219-03	.1505-04	.5255-02	.2583-02	.4529-13	.8109-10	.4579-07	.5374-15	.5996-12	.3004-08	.4287-07
.54	.363-01	.176-01	.1204 05	.313 01	.7539 01	.2573-01	.3656-02	.3219-03	.9968-05	.4723-02	.2452-02	.1517-13	.4460-10	.2937-07	.1345-15	.2256-12	.1693-08	.2772-07
.52	.282-01	.132-01	.1234 05	.329 01	.9486 01	.2581-01	.4004-02	.3219-03	.6385-05	.4175-02	.2304-02	.4686-14	.2320-10	.1815-07	.3029-16	.7642-13	.9033-09	.1727-07
.50	.215-01	.962-02	.1264 05	.346 01	.1213 02	.2589-01	.4364-02	.3219-03	.3934-05	.3619-02	.2140-02	.1323-14	.1133-10	.1074-07	.6044-17	.2463-13	.4531-09	.1030-07
.48	.162-01	.692-02	.1292 05	.363 01	.1573 02	.2596-01	.4729-02	.3219-03	.2317-05	.3066-02	.1964-02	.3367-15	.5146-11	.6050-08	.1051-17	.7069-14	.2119-09	.5644-08
.46	.121-01	.469-02	.1320 05	.380 01	.2068 02	.2607-01	.5093-02	.3219-03	.1295-05	.2525-02	.1775-02	.7612-16	.2151-11	.3217-08	.1556-18	.1776-14	.9163-10	.3127-08
.44	.891-02	.343-02	.1347 05	.398 01	.2747 02	.2617-01	.5449-02	.3219-03	.6799-06	.2010-02	.1579-02	.1500-16	.8163-12	.1599-08	.1914-19	.3869-15	.3622-10	.1563-08
.42	.654-02	.239-02	.1373 05	.416 01	.3675 02	.2627-01	.5786-02	.3219-03	.3316-06	.1535-02	.1379-02	.2521-17	.2768-12	.7334-09	.1894-20	.7096-16	.1293-10	.7207-09
.40	.479-02	.166-02	.1396 05	.434 01	.4926 02	.2637-01	.6096-02	.3219-03	.1482-06	.1116-02	.1179-02	.3518-18	.8231-13	.3062-09	.1451-21	.1065-16	.4103-11	.3022-09
.38	.353-02	.115-02	.1418 05	.452 01	.6567 02	.2647-01	.6369-02	.3219-03	.5965-07	.7638-03	.9847-03	.3946-19	.2098-13	.1143-09	.8222-23	.1259-17	.1138-11	.1132-09
.36	.262-02	.807-03	.1439 05	.470 01	.8747 02	.2656-01	.6600-02	.3219-03	.2123-07	.4871-03	.7998-03	.3423-20	.4462-14	.3742-10	.3264-24	.1124-18	.2698-12	.3716-10
.34	.197-02	.571-03	.1457 05	.487 01	.1151 03	.2665-01	.6786-02	.3219-03	.6532-08	.2859-03	.6297-03	.2192-21	.7665-15	.1049-10	.6513-26	.7212-20	.5328-13	.1044-10
.32	.149-02	.407-03	.1473 05	.505 01	.1500 03	.2672-01	.6928-02	.3219-03	.1692-08	.1524-03	.4783-03	.9799-23	.1033-15	.2451-11	.1351-27	.3132-21	.8460-14	.2443-11
.30	.114-02	.291-03	.1489 05	.524 01	.1942 03	.2679-01	.7033-02	.3219-03	.3577-09	.7269-04	.3484-03							
.28	.874-03	.206-03	.1503 05	.543 01	.2511 03	.2684-01	.7108-02	.3219-03	.5922-10	.3041-04	.2415-03							
.26	.680-03	.147-03	.1516 05	.566 01	.3259 03	.2688-01	.7159-02	.3219-03	.7286-11	.1088-04	.1577-03							
.24	.535-03	.103-03	.1529 05	.591 01	.4269 03	.2691-01	.7194-02	.3219-03	.6199-12	.3210-05	.9561-04							
.22	.377-03	.705-04	.1541 05	.620 01	.5673 03	.2693-01	.7217-02	.3219-03	.3303-13	.7427-06	.5283-04							
.20	.270-03	.470-04	.1553 05	.653 01	.7664 03	.2695-01	.7231-02	.3219-03	.9582-15	.1254-06	.2588-04							
.18	.198-03	.302-04	.1565 05	.692 01	.1066 04	.2696-01	.7238-02	.3219-03	.1236-16	.1392-07	.1080-04							
.16	.137-03	.188-04	.1576 05	.737 01	.1526 04	.2696-01	.7242-02	.3219-03	.5223-19	.8663-09	.3621-05							
.14	.916-04	.109-04	.1587 05	.790 01	.2269 04	.2696-01	.7243-02	.3219-03	.4478-22	.2357-10	.8880-06							
.12	.582-04	.593-05	.1598 05	.857 01	.3546 04	.2696-01	.7243-02	.3219-03	.3497-26	.1848-12	.1364-06							
.10	.346-04	.294-05	.1606 05	.941 01	.5935 04	.2696-01	.7244-02	.3219-03	.5888-32	.1968-15	.9932-08							
.08	.187-04	.127-05	.1616 05	.105 02	.1093 05	.2696-01	.7244-02	.3219-03		.6328-20	.1963-09							
.06	.868-05	.442-06	.1626 05	.122 02	.2334 05	.2696-01	.7244-02	.3219-03		.1823-27	.2877-12							
.04	.310-05	.105-06	.1637 05	.149 02	.6507 05	.2696-01	.7244-02	.3219-03			.6427-18							

Table 12. EQUILIBRIUM AIRFLOW EXPANSION

$T_o' = 7000°K$, $p_o' = 300$ atm., $\rho_o' = 1.285 \times 10^{-2}$ gm/cm^3,
$H_o = 6.304$, $(\rho u)_* = .7076$ at $T = .910$, $\bar{\mu}_o = 24.61$ gm/mole

T [23]	ρ	p	u' (ft/sec)	M	A	T_{N_2}	T_{O_2}	T_A
1.00	.100 01	.100 01	.0000 00	.000 00	—	.2426-01	.9907-03	.3219-03
.98	.910 00	.890 00	.2376 04	.436 00	.1500 01	.2433-01	.1039-02	.3219-03
.96	.827 00	.790 00	.3358 04	.624 00	.1169 01	.2438-01	.1093-02	.3219-03
.94	.749 00	.699 00	.4110 04	.773 00	.1053 01	.2444-01	.1153-02	.3219-03
.92	.678 00	.616 00	.4744 04	.903 00	.1009 01	.2449-01	.1218-02	.3219-03
.90	.612 00	.544 00	.5302 04	.102 01	.1000 01	.2454-01	.1291-02	.3219-03
.88	.550 00	.477 00	.5807 04	.113 01	.1015 01	.2459-01	.1371-02	.3219-03
.86	.494 00	.417 00	.6273 04	.124 01	.1047 01	.2464-01	.1460-02	.3219-03
.84	.442 00	.363 00	.6707 04	.134 01	.1096 01	.2468-01	.1558-02	.3219-03
.82	.393 00	.315 00	.7117 04	.145 01	.1159 01	.2472-01	.1666-02	.3219-03
.80	.349 00	.272 00	.7506 04	.155 01	.1236 01	.2477-01	.1785-02	.3219-03
.78	.308 00	.233 00	.7879 04	.165 01	.1336 01	.2481-01	.1915-02	.3219-03
.76	.271 00	.199 00	.8238 04	.175 01	.1453 01	.2485-01	.2058-02	.3219-03
.74	.237 00	.169 00	.8586 04	.186 01	.1596 01	.2490-01	.2214-02	.3219-03
.72	.206 00	.142 00	.8923 04	.196 01	.1766 01	.2495-01	.2384-02	.3219-03
.70	.177 00	.119 00	.9253 04	.207 01	.1976 01	.2500-01	.2569-02	.3219-03
.68	.152 00	.984-01	.9575 04	.218 01	.2230 01	.2505-01	.2768-02	.3219-03
.66	.129 00	.807-01	.9890 04	.230 01	.2541 01	.2511-01	.2981-02	.3219-03
.64	.109 00	.657-01	.1020 05	.242 01	.2924 01	.2516-01	.3210-02	.3219-03
.62	.908-01	.528-01	.1050 05	.254 01	.3401 01	.2525-01	.3452-02	.3219-03
.60	.751-01	.421-01	.1080 05	.266 01	.3996 01	.2533-01	.3706-02	.3219-03
.58	.615-01	.331-01	.1109 05	.279 01	.4752 01	.2541-01	.3976-02	.3219-03
.56	.499-01	.258-01	.1138 05	.293 01	.5711 01	.2550-01	.4253-02	.3219-03
.54	.401-01	.199-01	.1166 05	.307 01	.6939 01	.2560-01	.4537-02	.3219-03
.52	.319-01	.152-01	.1194 05	.321 01	.8519 01	.2570-01	.4826-02	.3219-03
.50	.252-01	.114-01	.1220 05	.336 01	.1056 02	.2580-01	.5115-02	.3219-03
.48	.197-01	.857-02	.1246 05	.351 01	.1321 02	.2591-01	.5399-02	.3219-03
.46	.154-01	.636-02	.1270 05	.366 01	.1663 02	.2602-01	.5673-02	.3219-03
.44	.119-01	.470-02	.1293 05	.381 01	.2105 02	.2614-01	.5933-02	.3219-03
.42	.923-02	.346-02	.1316 05	.397 01	.2672 02	.2625-01	.6173-02	.3219-03
.40	.715-02	[illegible]	.1336 05	.413 01	.3395 02	.2636-01	.6389-02	.3219-03
.38	.555-02	.187-02	.1356 05	.428 01	.4312 02	.2646-01	.6577-02	.3219-03
.36	.432-02	.136-02	.1374 05	.445 01	.5470 02	.2656-01	.6737-02	.3219-03
.34	.337-02	.101-02	.1391 05	.461 01	.6932 02	.2664-01	.6866-02	.3219-03
.32	.263-02	.744-03	.1406 05	.476 01	.8766 02	.2672-01	.6973-02	.3219-03
.30	.204-02	[illegible]	.1421 05	.497 01	.1117 03	.2679-01	.7055-02	.3219-03
.28	.156-02	.372-03	.1436 05	.517 01	.1428 03	.2684-01	.7117-02	.3219-03
.26	.121-02	.279-03	.1449 05	.540 01	.1843 03	.2688-01	.7163-02	.3219-03
.24	.922-03	.196-03	.1463 05	.565 01	.2407 03	.2691-01	.7195-02	.3219-03
.22	.689-03	.134-03	.1475 05	.594 01	.3194 03	.2693-01	.7217-02	.3219-03
.20	.505-03	[illegible]	.1488 05	.626 01	.4322 03	.2695-01	.7231-02	.3219-03
.18	.361-03	.575-04	.1500 05	.663 01	.5994 03	.2696-01	.7238-02	.3219-03
.16	.250-03	.354-04	.1512 05	.707 01	.8570 03	.2696-01	.7242-02	.3219-03
.14	.167-03	.207-04	.1523 05	.759 01	.1274 04	.2696-01	.7243-02	.3219-03
.12	.106-03	.113-04	.1534 05	.823 01	.1990 04	.2696-01	.7243-02	.3219-03
.10	.631-04	.556-05	.1545 05	.904 01	.3326 04	.2696-01	.7244-02	.3219-03
.08	.341-04	.241-05	.1556 05	.101 02	.6124 04	.2696-01	.7244-02	.3219-03
.06	.156-04	.841-06	.1566 05	.117 02	.1307 05	.2696-01	.7244-02	.3219-03
.04	.565-05	.200-06	.1576 05	.144 02	.3643 05	.2696-01	.7244-02	.3219-03

T	T_N	T_O	T_{NO}	$T_{N_2^+}$	$T_{O_2^+}$	T_{NO^+}	T_{N^+}	T_{O^+}	T_{O^-}	T_{e^-}
1.00	.9514-03	.8058-02	.4441-02	.1344-07	.5138-07	.5485-05	.2104-08	.1701-07	.1966-05	.3601-05
.98	.8460-03	.7980-02	.4421-02	.9524-08	.4367-07	.4790-05	.1386-08	.1267-07	.1687-05	.3171-05
.96	.7480-03	.7893-02	.4401-02	.6646-08	.3684-07	.4159-05	.6964-09	.9613-08	.1437-05	.2776-05
.94	.6572-03	.7796-02	.4381-02	.4563-08	.3083-07	.3590-05	.5693-09	.7075-08	.1216-05	.2417-05
.92	.5737-03	.7687-02	.4359-02	.3080-08	.2556-07	.3078-05	.3529-09	.5127-08	.1022-05	.2090-05
.90	.4973-03	.7566-02	.4336-02	.2041-08	.2102-07	.2621-05	.2137-09	.3655-08	.8519-06	.1796-05
.88	.4279-03	.7431-02	.4310-02	.1327-08	.1710-07	.2215-05	.1263-09	.2560-08	.7041-06	.1532-05
.86	.3653-03	.7283-02	.4282-02	.8450-09	.1376-07	.1856-05	.7266-10	.1760-08	.5764-06	.1296-05
.84	.3092-03	.7119-02	.4250-02	.5265-09	.1094-07	.1542-05	.4065-10	.1186-08	.4670-06	.1066-05
.82	.2594-03	.6940-02	.4214-02	.3206-09	.8561-08	.1269-05	.2206-10	.7823-09	.3741-06	.9050-06
.80	.2156-03	.6744-02	.4172-02	.1904-09	.6638-08	.1034-05	.1161-10	.5042-09	.2959-06	.7456-06
.78	.1773-03	.6531-02	.4125-02	.1102-09	.5056-08	.8333-06	.5904-11	.3170-09	.2309-06	.6079-06
.76	.1443-03	.6300-02	.4070-02	.6196-10	.3766-08	.6635-06	.2894-11	.1941-09	.1774-06	.4901-06
.74	.1160-03	.6051-02	.4007-02	.3361-10	.2764-08	.5215-06	.1365-11	.1155-09	.1341-06	.3903-06
.72	.9211-04	.5784-02	.3935-02	.1786-10	.2006-08	.4041-06	.6166-12	.6662-10	.9946-07	.3067-06
.70	.7212-04	.5498-02	.3852-02	.9109-11	.1413-08	.3084-06	.2664-12	.3715-10	.7228-07	.2376-06
.68	.5563-04	.5194-02	.3757-02	.4473-11	.9719-09	.2314-06	.1095-12	.1997-10	.5134-07	.1811-06
.66	.4222-04	.4873-02	.3651-02	.2108-11	.6506-09	.1705-06	.4268-13	.1031-10	.3556-07	.1356-06
.64	.3146-04	.4536-02	.3531-02	.9499-12	.4229-09	.1231-06	.1568-13	.5098-11	.2395-07	.9961-07
.62	.2298-04	.4185-02	.3397-02	.4075-12	.2660-09	.8694-07	.5404-14	.2400-11	.1564-07	.7157-07
.60	.1641-04	.3821-02	.3249-02	.1656-12	.1614-09	.5988-07	.1734-14	.1071-11	.9860-08	.5019-07
.58	.1143-04	.3448-02	.3088-02	.6340-13	.9403-10	.4012-07	.5142-15	.4499-12	.5962-08	.3424-07
.56	.7745-05	.3069-02	.2912-02	.2272-13	.5237-10	.2606-07	.1396-15	.1768-12	.3476-08	.2264-07
.54	.5081-05	.2688-02	.2724-02	.7559-14	.2772-10	.1635-07	.3435-16	.6439-13	.1924-08	.1445-07
.52	.3214-05	.2312-02	.2524-02	.2314-14	.1366-10	.9855-08	.7556-17	.2152-13	.1009-08	.8860-08
.50	.1949-05	.1945-02	.2313-02	.6449-15	.6494-11	.5676-08	.1465-17	.6525-14	.4977-09	.5187-08
.48	.1127-05	.1594-02	.2095-02	.1615-15	.2826-11	.3105-08	.2456-18	.1766-14	.2292-09	.2879-08
.46	.6158-06	.1268-02	.1872-02	.3582-16	.1130-11	.1599-08	.3489-19	.4211-15	.9762-10	.1503-08
.44	.3154-06	.9734-03	.1647-02	.6905-17	.4097-12	.7683-09	.4093-20	.8636-16	.3606-10	.7307-09
.42	.1498-06	.7164-03	.1424-02	.1133-17	.1328-12	.3405-09	.3847-21	.1489-16	.1342-10	.3272-09
.40	.6510-07	.5021-03	.1207-02	.1541-18	.3781-13	.1374-09	.2795-22	.2100-17	.4212-11	.1332-09
.38	.2553-07	.3323-03	.1000-02	.1687-19	.9262-14	.4967-10	.1505-23	.2342-18	.1156-11	.4852-10
.36	.8878-08	.2058-03	.8080-03	.1431-20	.1905-14	.1581-10	.5709-25	.1987-19	.2726-12	.1554-10
.34	.2680-08	.1180-03	.6355-03	.9002-22	.3194-15	.4334-11	.1435-26	.1223-20	.5356-13	.4261-11
.32	.6849-09	.6189-04	.4798-03	.3970-23	.4210-16	.9962-12	.2215-28	.5152-22	.8499-14	.9877-12
.30	.1434-09	.2920-04	.3489-03							
.28	.2363-10	.1214-04	.2416-03							
.26	.2899-11	.4330-05	.1577-03							
.24	.2464-12	.1276-05	.9562-04							
.22	.1312-13	.2951-06	.5283-04							
.20	.3807-15	.4983-07	.2588-04							
.18	.4910-17	.5530-08	.1080-04							
.16	.2075-19	.3442-09	.3621-05							
.14	.1779-22	.9364-11	.8880-06							
.12	.1390-26	.7340-13	.1364-06							
.10	.2339-32	.7821-16	.9932-08							
.08		.2514-20	.1963-09							
.06		.7242-28	.2877-12							
.04			.6427-18							

Table 13. EQUILIBRIUM AIRFLOW EXPANSION

$T_o' = 7000°K$, $p_o' = 1000$ atm., $\rho_o' = 4.460 \times 10^{-2}$ gm/cm^3,

$H_o = 5.949$, $(\rho u)_* = .6962$ at $T = .904$, $\bar{\mu}_o = 25.62$ gm/mole

24 T	ρ	p	u' (ft/sec)	M	A	T_{N_2}	T_{O_2}	T_A	T_N	T_O	T_{NO}	$T_{N_2^+}$	$T_{O_2^+}$	T_{NO^+}	T_{N^+}	T_{O^+}	T_{O^-}	T_{e^-}
1.00	.100 01	.100 01	.0000 00	.000 00	∞	.2170-01	.7178-04	.3219-03	.9135-02	.1296-01	.1357-02	.6946-06	.9247-07	.2625-04	.8530-06	.9703-06	.1124-05	.2773-04
.98	.864 00	.842 00	.3334 04	.545 00	.1278 01	.2201-01	.7168-04	.3219-03	.8545-02	.1299-01	.1330-02	.5450-06	.8065-07	.2393-04	.6469-06	.8075-06	.9442-06	.2507-04
.96	.744 00	.706 00	.4710 04	.779 00	.1051 01	.2232-01	.7174-04	.3219-03	.7960-02	.1302-01	.1304-02	.4220-06	.6995-07	.2173-04	.4828-06	.6650-06	.7897-06	.2256-04
.94	.639 00	.589 00	.5761 04	.967 00	.1001 01	.2262-01	.7201-04	.3219-03	.7381-02	.1304-01	.1278-02	.3222-06	.6029-07	.1963-04	.3542-06	.5415-06	.6572-06	.2026-04
.92	.546 00	.490 00	.6642 04	.113 01	.1015 01	.2292-01	.7251-04	.3219-03	.6809-02	.1307-01	.1254-02	.2422-06	.5165-07	.1766-04	.2550-06	.4356-06	.5443-06	.1810-04
.90	.466 00	.407 00	.7412 04	.128 01	.1066 01	.2322-01	.7331-04	.3219-03	.6246-02	.1309-01	.1230-02	.1791-06	.4395-07	.1579-04	.1799-06	.3458-06	.4465-06	.1609-04
.88	.396 00	.336 00	.8103 04	.142 01	.1147 01	.2350-01	.7447-04	.3219-03	.5693-02	.1312-01	.1208-02	.1301-06	.3714-07	.1404-04	.1241-06	.2706-06	.3676-06	.1423-04
.86	.336 00	.277 00	.8730 04	.155 01	.1255 01	.2378-01	.7606-04	.3219-03	.5153-02	.1313-01	.1188-02	.9263-07	.3116-07	.1240-04	.8353-07	.2084-06	.2998-06	.1252-04
.84	.284 00	.228 00	.9307 04	.168 01	.1391 01	.2406-01	.7819-04	.3219-03	.4628-02	.1315-01	.1169-02	.6458-07	.2595-07	.1088-04	.5475-07	.1577-06	.2431-06	.1094-04
.82	.240 00	.187 00	.9840 04	.180 01	.1557 01	.2432-01	.8098-04	.3219-03	.4121-02	.1316-01	.1153-02	.4399-07	.2144-07	.9473-05	.3464-07	.1172-06	.1961-06	.9494-05
.80	.203 00	.153 00	.1034 05	.192 01	.1757 01	.2457-01	.8460-04	.3219-03	.3633-02	.1317-01	.1139-02	.2922-07	.1756-07	.8178-05	.2147-07	.8523-07	.1573-06	.8174-05
.78	.171 00	.125 00	.1080 05	.203 01	.1994 01	.2481-01	.8927-04	.3219-03	.3169-02	.1317-01	.1128-02	.1888-07	.1426-07	.6996-05	.1277-07	.6061-07	.1255-06	.6977-05
.76	.144 00	.102 00	.1123 05	.215 01	.2274 01	.2503-01	.9527-04	.3219-03	.2731-02	.1317-01	.1121-02	.1183-07	.1148-07	.5925-05	.7300-08	.4204-07	.9953-07	.5898-05
.74	.122 00	.835-01	.1163 05	.226 01	.2602 01	.2524-01	.1030-03	.3219-03	.2322-02	.1316-01	.1118-02	.7177-08	.9146-08	.4962-05	.3999-08	.2836-07	.7849-07	.4932-05
.72	.103 00	.683-01	.1200 05	.236 01	.2984 01	.2543-01	.1130-03	.3219-03	.1945-02	.1314-01	.1120-02	.4199-08	.7211-08	.4106-05	.2090-08	.1857-07	.6152-07	.4076-05
.70	.871-01	.560-01	.1235 05	.246 01	.3425 01	.2559-01	.1259-03	.3219-03	.1604-02	.1311-01	.1127-02	.2362-08	.5621-08	.3352-05	.1037-08	.1176-07	.4790-07	.3325-05
.68	.739-01	.459-01	.1266 05	.257 01	.3933 01	.2574-01	.1427-03	.3219-03	.1298-02	.1306-01	.1139-02	.1273-08	.4327-08	.2697-05	.4864-09	.7188-08	.3703-07	.2673-05
.66	.628-01	.376-01	.1296 05	.266 01	.4516 01	.2587-01	.1649-03	.3219-03	.1031-02	.1300-01	.1158-02	.6554-09	.3286-08	.2136-05	.2146-09	.4220-08	.2840-07	.2116-05
.64	.535-01	.311-01	.1327 05	.276 01	.5185 01	.2597-01	.1942-03	.3219-03	.8015-03	.1291-01	.1184-02	.3209-09	.2457-08	.1662-05	.8864-10	.2375-08	.2157-07	.1645-05
.62	.457-01	.256-01	.1354 05	.286 01	.5955 01	.2605-01	.2333-03	.3219-03	.6093-03	.1280-01	.1216-02	.1489-09	.1806-08	.1269-05	.3410-10	.1276-08	.1618-07	.1256-05
.60	.390-01	.211-01	.1379 05	.296 01	.6849 01	.2611-01	.2857-03	.3219-03	.4522-03	.1266-01	.1255-02	.6524-10	.1300-08	.9488-06	.1216-10	.6522-09	.1196-07	.9389-06
.58	.332-01	.173-01	.1404 05	.307 01	.7903 01	.2615-01	.3564-03	.3219-03	.3272-03	.1247-01	.1301-02	.2688-10	.9145-09	.6938-06	.4000-11	.3160-09	.8677-08	.6864-06
.56	.281-01	.141-01	.1426 05	.316 01	.9177 01	.2617-01	.4516-03	.3219-03	.2306-03	.1223-01	.1350-02	.1038-10	.6255-09	.4950-06	.1209-11	.1445-09	.6143-08	.4897-06
.54	.236-01	.115-01	.1453 05	.330 01	.1078 02	.2616-01	.5793-03	.3219-03	.1581-03	.1193-01	.1401-02	.3741-11	.4140-09	.3439-06	.3340-12	.6217-10	.4216-08	.3402-06
.52	.195-01	.895-02	.1477 05	.344 01	.1261 02	.2618-01	.7489-03	.3219-03	.1053-03	.1154-01	.1449-02	.1253-11	.2634-09	.2320-06	.8399-13	.2503-10	.2783-08	.2296-06
.50	.157-01	.692-02	.1502 05	.360 01	.1557 02	.2616-01	.9705-03	.3219-03	.6807-04	.1106-01	.1489-02	.3884-12	.1599-09	.1516-06	.1911-13	.9379-11	.1750-08	.1500-06
.48	.124-01	.519-02	.1529 05	.377 01	.1942 02	.2616-01	.1253-02	.3219-03	.4263-04	.1047-01	.1513-02	.1107-12	.9169-10	.9553-07	.3909-14	.3250-11	.1037-08	.9459-07
.46	.945-02	.376-02	.1557 05	.396 01	.2504 02	.2619-01	.1604-02	.3219-03	.2578-04	.9762-02	.1517-02	.2875-13	.4948-10	.5782-07	.7113-15	.1032-11	.5725-09	.5730-07
.44	.693-02	.261-02	.1586 05	.417 01	.3352 02	.2621-01	.2026-02	.3219-03	.1500-04	.8941-02	.1493-02	.6738-14	.2471-10	.3341-07	.1136-15	.2970-12	.2909-09	.3315-07
.42	.486-02	.173-02	.1617 05	.440 01	.4684 02	.2624-01	.2518-02	.3219-03	.8343-05	.8012-02	.1440-02	.1403-14	.1130-10	.1630-07	.1560-16	.7621-13	.1343-09	.1816-07
.40	.326-02	.109-02	.1649 05	.465 01	.6848 02	.2626-01	.3071-02	.3219-03	.4397-05	.6990-02	.1355-02	.2545-15	.4668-11	.9408-08	.1796-17	.1709-13	.5552-10	.9357-08
.38	.209-02	.652-03	.1681 05	.491 01	.1049 03	.2634-01	.3674-02	.3219-03	.2170-05	.5897-02	.1242-02	.3923-16	.1710-11	.4482-06	.1674-18	.3259-14	.2022-10	.4463-08
.36	.128-02	.373-03	.1714 05	.520 01	.1676 03	.2641-01	.4308-02	.3219-03	.9866-06	.4766-02	.1105-02	.4970-17	.5430-12	.1945-08	.1206-19	.5096-15	.6367-11	.1939-08
.34	.757-03	.205-03	.1745 05	.550 01	.2766 03	.2649-01	.4948-02	.3219-03	.4042-06	.3640-02	.9501-03	.4958-18	.1451-12	.7514-09	.6321-21	.6220-16	.1692-11	.7499-09
.32	.436-03	.110-03	.1776 05	.581 01	.4736 03	.2657-01	.5562-02	.3219-03	.1448-06	.2577-02	.7857-03	.3682-19	.3129-13	.2504-09	.2220-22	.5544-17	.3682-12	.2500-09
.30	.253-03	.569-04	.1803 05	.612 01	.8059 03	.2665-01	.6111-02	.3219-03	.4354-07	.1644-02	.6209-03	.1892-20	.5167-14	.6697-10	.4693-24	.3302-18	.6318-13	.6692-10
.28	.151-03	.325-04	.1827 05	.642 01	.1333 04	.2673-01	.6554-02	.3219-03	.1043-07	.9136-03	.4652-03	.6115-22	.6094-15	.1468-10	.5193-26	.1171-19	.8146-14	.1467-10
.26	.934-04	.169-04	.1847 05	.670 01	.2090 04	.2680-01	.6867-02	.3219-03	.1870-08	.4252-03	.3275-03	.1105-23	.4729-16	.2356-11		.2158-21	.7420-15	.2355-11
.24	.641-04	.117-04	.1863 05	.694 01	.3064 04	.2685-01	.7056-02	.3219-03	.2345-09	.1601-03	.2142-03							
.22	.449-04	.749-05	.1877 05	.720 01	.4368 04	.2690-01	.7156-02	.3219-03	.1899-10	.4711-04	.1283-03							
.20	.319-04	.484-05	.1889 05	.750 01	.6107 04	.2693-01	.7204-02	.3219-03	.8899-12	.1033-04	.6899-04							
.18	.225-04	.306-05	.1900 05	.790 01	.8628 04	.2695-01	.7227-02	.3219-03	.2039-13	.1558-05	.3219-04							
.16	.154-04	.187-05	.1911 05	.839 01	.1251 05	.2696-01	.7237-02	.3219-03	.1759-15	.1416-06	.1238-04							
.14	.102-04	.108-05	.1922 05	.898 01	.1884 05	.2696-01	.7242-02	.3219-03	.3762-18	.6240-08	.3621-05							
.12	.639-05	.580-06	.1932 05	.972 01	.2985 05	.2696-01	.7243-02	.3219-03	.9912-22	.9283-10	.7026-06							
.10	.375-05	.284-06	.1942 05	.107 02	.5061 05	.2696-01	.7244-02	.3219-03	.9120-27	.2417-12	.7085-07							
.08	.200-05	.121-06	.1952 05	.119 02	.9459 05	.2696-01	.7244-02	.3219-03	.2351-34	.2956-16	.2278-08							
.06	.914-06	.415-07	.1961 05	.138 02	.2054 06	.2696-01	.7244-02	.3219-03		.7846-23	.7499-11							

Table 14. EQUILIBRIUM AIRFLOW EXPANSION

$T_o' = 8000°K$, $p_o' = 100$ atm., $\rho_o' = 3.340 \times 10^{-3}$ gm/cm^3,

$H_o = 7.951$, $(\rho u)_* = .7392$ at $T = .936$, $\bar{\mu}_o = 21.93$ gm/mole

$T^{.35}$	ρ	p	u' (ft/sec)	M	A	τ_{N_2}	τ_{O_2}	τ_A	τ_N	τ_O	τ_{NO}	$\tau_{N_2^+}$	$\tau_{O_2^+}$	τ_{NO^+}	τ_{N^+}	τ_{O^+}	τ_{O^-}	τ_{e^-}
1.00	.100 01	.100 01	.0000 00	.000 00	∞	.2316-01	.1892-03	.3219-03	.5298-02	.1181-01	.2277-02	.3401-06	.1118-06	.2020-04	.2269-06	.4056-06	.2233-05	.1525-04
.98	.884 00	.863 00	.3002 04	.499 00	.1356 01	.2338-01	.1932-03	.3219-03	.4887-02	.1183-01	.2251-02	.2604-06	.9776-07	.1821-04	.1664-06	.3308-06	.1917-05	.1716-04
.96	.760 00	.742 00	.4237 04	.713 00	.1090 01	.2360-01	.1976-03	.3219-03	.4486-02	.1185-01	.2226-02	.1967-06	.8500-07	.1635-04	.1199-06	.2668-06	.1621-05	.1570-04
.94	.667 00	.637 00	.5177 04	.863 00	.1013 01	.2380-01	.2033-03	.3219-03	.4097-02	.1186-01	.2204-02	.1463-06	.7348-07	.1461-04	.8486-07	.2125-06	.1385-05	.1374-04
.92	.604 00	.546 00	.5963 04	.103 01	.1001 01	.2400-01	.2099-03	.3219-03	.3720-02	.1187-01	.2183-02	.1071-06	.6314-07	.1298-04	.5884-07	.1671-06	.1172-05	.1221-04
.90	.530 00	.466 00	.6646 04	.116 01	.1023 01	.2420-01	.2177-03	.3219-03	.3356-02	.1187-01	.2164-02	.7710-07	.5391-07	.1147-04	.3992-07	.1295-06	.9857-06	.1079-04
.88	.464 00	.398 00	.7261 04	.129 01	.1069 01	.2438-01	.2270-03	.3219-03	.3006-02	.1187-01	.2149-02	.5446-07	.4571-07	.1008-04	.2645-07	.9887-07	.8245-06	.9476-05
.86	.406 00	.339 00	.7817 04	.140 01	.1135 01	.2455-01	.2382-03	.3219-03	.2673-02	.1187-01	.2136-02	.3770-07	.3848-07	.8793-05	.1708-07	.7421-07	.6863-06	.8273-05
.84	.355 00	.286 00	.8326 04	.152 01	.1219 01	.2472-01	.2516-03	.3219-03	.2356-02	.1185-01	.2126-02	.2554-07	.3215-07	.7616-05	.1073-07	.5471-07	.5691-06	[illegible]
.82	.310 00	.245 00	.8796 04	.162 01	.1321 01	.2487-01	.2676-03	.3219-03	.2058-02	.1182-01	.2120-02	.1690-07	.2664-07	.6545-05	.6540-08	.3954-07	.4688-06	[illegible]
.80	.271 00	.206 00	.9236 04	.173 01	.1441 01	.2501-01	.2873-03	.3219-03	.1780-02	.1179-01	.2118-02	.1091-07	.2188-07	.5577-05	.3859-08	.2798-07	.3839-06	[illegible]
.78	.236 00	.176 00	.9645 04	.183 01	.1582 01	.2514-01	.3109-03	.3219-03	.1523-02	.1174-01	.2120-02	.6852-08	.1780-07	.4709-05	.2199-08	.1935-07	.3122-06	[illegible]
.76	.206 00	.149 00	.1003 05	.192 01	.1745 01	.2525-01	.3395-03	.3219-03	.1288-02	.1168-01	.2126-02	.4181-08	.1433-07	.3935-05	.1226-08	.1306-07	.2522-06	[illegible]
.74	.179 00	.126 00	.1039 05	.202 01	.1933 01	.2535-01	.3745-03	.3219-03	.1076-02	.1160-01	.2137-02	.2472-08	.1140-07	.3252-05	.6353-09	.8573-08	.2017-06	[illegible]
.72	.156 00	.106 00	.1073 05	.212 01	.2150 01	.2544-01	.4172-03	.3219-03	.8862-03	.1150-01	.2152-02	.1414-08	.8962-08	.2656-05	.3203-09	.5469-08	[illegible]	[illegible]
.70	.136 00	.895-01	.1106 05	.221 01	.2400 01	.2551-01	.4695-03	.3219-03	.7195-03	.1137-01	.2172-02	.7802-09	.6945-08	.2141-05	.1541-09	.3382-08	.1255-06	[illegible]
.68	.118 00	.751-01	.1137 05	.231 01	.2691 01	.2558-01	.5336-03	.3219-03	.5751-03	.1122-01	.2195-02	.4143-09	.5297-08	.1702-05	.7055-10	.2022-08	.9727-07	[illegible]
.66	.102 00	.628-01	.1167 05	.241 01	.3031 01	.2562-01	.6124-03	.3219-03	.4522-03	.1104-01	.2221-02	.2112-09	.3970-08	.1332-05	.3262-10	.1166-08	.7417-07	[illegible]
.64	.877-01	.522-01	.1196 05	.251 01	.3434 01	.2566-01	.7091-03	.3219-03	.3494-03	.1082-01	.2248-02	.1030-09	.2915-08	.1026-05	.1255-10	.6465-09	.5561-07	[illegible]
.62	.751-01	.431-01	.1225 05	.262 01	.3920 01	.2569-01	.8273-03	.3219-03	.2650-03	.1056-01	.2274-02	.4799-10	.2092-08	.7753-06	.4845-11	.3438-09	[illegible]	[illegible]
.60	.637-01	.353-01	.1253 05	.274 01	.4514 01	.2571-01	.9711-03	.3219-03	.1970-03	.1025-01	.2297-02	.2127-10	.1463-08	.5745-06	.1754-11	.1747-09	.2924-07	[illegible]
.58	.535-01	.285-01	.1282 05	.286 01	.5257 01	.2573-01	.1145-02	.3219-03	.1435-03	.9884-02	.2313-02	.8932-11	.9921-09	.4166-06	.5923-12	.8454-10	.2136-07	[illegible]
.56	.443-01	.226-01	.1310 05	.299 01	.6205 01	.2575-01	.1353-02	.3219-03	.1022-03	.9462-02	.2318-02	.3543-11	.6502-09	.2948-06	.1858-12	.3878-10	.1377-07	[illegible]
.54	.362-01	.177-01	.1339 05	.312 01	.7444 01	.2577-01	.1600-02	.3219-03	.7104-04	.8978-02	.2310-02	.1320-11	.4097-09	.2032-06	.5379-13	.1677-10	.8855-08	[illegible]
.52	.287-01	.135-01	.1366 05	.326 01	.9102 01	.2580-01	.1887-02	.3219-03	.4810-04	.8430-02	.2283-02	.4592-12	.2468-09	.1359-06	.1426-13	.6798-11	.5467-08	[illegible]
.50	.227-01	.101-01	.1396 05	.345 01	.1137 02	.2583-01	.2217-02	.3219-03	.3162-04	.7817-02	.2235-02	.1481-12	.1412-09	.8796-07	.3432-14	.2563-11	.3201-08	[illegible]
.48	.175-01	.736-02	.1426 05	.362 01	.1456 02	.2587-01	.2590-02	.3219-03	.2011-04	.7143-02	.2163-02	.4389-13	.7623-10	.5479-07	.7402-15	.9901-12	.1763-08	[illegible]
.46	.129-01	.520-02	.1459 05	.381 01	.1913 02	.2592-01	.3004-02	.3219-03	.1231-04	.6413-02	.2065-02	.1181-13	.3847-10	.3268-07	.1410-15	.2815-12	[illegible]	[illegible]
.44	.930-02	.357-02	.1490 05	.401 01	.2585 02	.2599-01	.3454-02	.3219-03	.7212-05	.5637-02	.1942-02	.2849-14	.1796-10	.1853-07	.2328-16	.7984-13	[illegible]	[illegible]
.42	.650-02	.237-02	.1520 05	.423 01	.3593 02	.2606-01	.3934-02	.3219-03	.4007-05	.4826-02	.1794-02	.6051-15	.7667-11	.9900-08	.3254-17	.1994-13	.1867-09	[illegible]
.40	.455-02	.153-02	.1551 05	.445 01	.5133 02	.2615-01	.4431-02	.3219-03	.2090-05	.4000-02	.1624-02	.1107-15	.2944-11	.4928-08	.3732-18	.4277-14	.7266-10	[illegible]
.38	.304-02	.966-03	.1581 05	.469 01	.7511 02	.2624-01	.4934-02	.3219-03	.1009-05	.3182-02	.1437-02	.1698-16	.9976-12	.2252-08	.3381-19	.7641-15	.2512-10	[illegible]
.36	.200-02	.597-03	.1610 05	.493 01	.1119 03	.2634-01	.5424-02	.3219-03	.4425-06	.2402-02	.1238-02	.2108-17	.2908-12	.9270-09	.2301-20	.1092-15	.7545-11	[illegible]
.34	.131-02	.369-03	.1637 05	.518 01	.1662 03	.2644-01	.5879-02	.3219-03	.1724-06	.1694-02	.1035-02	.2028-18	.7062-13	.3354-09	.1105-21	.1186-16	.1921-11	[illegible]
.32	.862-03	.224-03	.1661 05	.543 01	.2516 03	.2654-01	.6279-02	.3219-03	.5792-07	.1096-02	.8344-03	.1430-19	.1373-13	.1034-09	.3453-23	.9165-18	.4026-12	.1035-09
.30	.576-03	.140-03	.1683 05	.567 01	.3705 03	.2664-01	.6603-02	.3219-03	.1618-07	.6354-03	.6453-03	.6900-21	.2038-14	.2616-10	.6364-25	.4656-19	.6690-13	.2609-10
.28	.399-03	.890-04	.1702 05	.590 01	.5312 03	.2672-01	.6844-02	.3219-03	.3605-08	.3227-03	.4754-03	.2092-22	.2178-15	.5201-11	.6143-27	.1416-20	.8411-14	[illegible]-11
.26	.285-03	.590-04	.1719 05	.612 01	.7417 03	.2680-01	.7008-02	.3219-03	.6099-09	.1401-03	.3308-03							
.24	.204-03	.393-04	.1733 05	.636 01	.1016 04	.2685-01	.7111-02	.3219-03	.7372-10	.5051-04	.2150-03							
.22	.148-03	.262-04	.1747 05	.663 01	.1391 04	.2690-01	.7172-02	.3219-03	.5866-11	.1456-04	.1285-03							
.20	.107-03	.172-04	.1759 05	.696 01	.1918 04	.2693-01	.7207-02	.3219-03	.2731-12	.3172-05	.6900-04							
.18	.754-04	.109-04	.1771 05	.736 01	.2696 04	.2695-01	.7227-02	.3219-03	.6247-14	.4775-06	.3219-04							
.16	.517-04	.663-05	.1783 05	.782 01	.3907 04	.2696-01	.7237-02	.3219-03	.5388-16	.4335-07	.1238-04							
.14	.342-04	.363-05	.1794 05	.839 01	.5679 04	.2696-01	.7242-02	.3219-03	.1152-18	.1911-08	.3621-05							
.12	.215-04	.206-05	.1805 05	.906 01	.9305 04	.2696-01	.7243-02	.3219-03	.3036-22	.2843-10	.7026-06							
.10	.126-04	.101-05	.1816 05	.997 01	.1577 05	.2696-01	.7244-02	.3219-03	.2793-27	.7402-13	.7085-07							
.08	.670-05	.429-06	.1826 05	.112 02	.2945 05	.2696-01	.7244-02	.3219-03	.7198-35	.9053-17	.2278-08							
.06	.307-05	.146-06	.1836 05	.129 02	.6389 05	.2696-01	.7244-02	.3219-03		.2403-23	.7499-11							

Table 15. EQUILIBRIUM AIRFLOW EXPANSION

$T_o' = 8000°K$, $p_o' = 300$ atm., $\rho_o' = 1.060 \times 10^{-2}$ gm/cm^3,

$H_o = 6.999$, $(\rho u)_* = .7234$ at $T = .924$, $\bar{\mu}_o = 23.20$ gm/mole

25 T	ρ	p	u' (ft/sec.)	M	A	γ_{N_2}	γ_{O_2}	γ_A	γ_N	γ_O	γ_{NO}	$\gamma_{N_2^+}$	$\gamma_{O_2^+}$	γ_{NO^+}	γ_{N^+}	γ_{O^+}	γ_{O^-}	γ_{e^-}
1.00	.100 01	.100 01	.0000 00	.000 00	—	.2371-01	.4078-03	.3219-03	.2661-02	.9910-02	.3622-02	.1032-06	.1296-06	.1506-04	.5744-07	.1396-06	.3997-05	.1157-04
.98	.902 00	.881 00	.2705 04	.436 00	.1450 01	.2385-01	.4846-03	.3219-03	.2608-02	.9900-02	.3601-02	.1226-06	.1132-06	.1344-04	.4097-07	.1276-06	.3466-05	.1030-04
.96	.815 00	.775 00	.3820 04	.632 00	.1141 01	.2398-01	.5034-03	.3219-03	.2385-02	.9884-02	.3581-02	.9079-07	.9826-07	.1194-04	.2872-07	.1011-06	.2995-05	.9267-05
.94	.731 00	.680 00	.4670 04	.807 00	.1038 01	.2411-01	.5247-03	.3219-03	.2154-02	.9862-02	.3562-02	.6626-07	.8478-07	.1058-04	.1976-07	.7902-07	.2575-05	.8234-05
.92	.658 00	.595 00	.5385 04	.942 00	.1003 01	.2423-01	.5487-03	.3219-03	.1914-02	.9832-02	.3546-02	.4761-07	.7266-07	.9265-05	.1333-07	.6094-07	.2202-05	.7277-05
.90	.587 00	.520 00	.6007 04	.106 01	.1004 01	.2434-01	.5761-03	.3219-03	.1706-02	.9793-02	.3531-02	.3363-07	.6166-07	.8116-05	.8802-08	.4633-07	.1873-05	.6395-05
.88	.523 00	.454 00	.6567 04	.118 01	.1027 01	.2444-01	.6073-03	.3219-03	.1511-02	.9745-02	.3519-02	.2333-07	.5225-07	.7053-05	.5666-08	.3466-07	.1583-05	.5586-05
.86	.465 00	.394 00	.7078 04	.129 01	.1067 01	.2454-01	.6430-03	.3219-03	.1326-02	.9686-02	.3508-02	.1566-07	.4376-07	.6067-05	.3576-08	.2553-07	.1330-05	.4848-05
.84	.418 00	.342 00	.7550 04	.139 01	.1122 01	.2463-01	.6840-03	.3219-03	.1158-02	.9614-02	.3499-02	.1059-07	.3636-07	.5216-05	.2193-08	.1847-07	.1110-05	.4172-05
.82	.372 00	.296 00	.7995 04	.149 01	.1192 01	.2471-01	.7310-03	.3219-03	.1001-02	.9526-02	.3491-02	.6966-08	.2991-07	.4434-05	.1306-08	.1311-07	.9186-06	.3566-05
.80	.330 00	.258 00	.8404 04	.159 01	.1278 01	.2479-01	.7852-03	.3219-03	.8573-03	.9427-02	.3485-02	.4401-08	.2434-07	.3737-05	.7505-09	.9110-08	.7540-06	.3022-05
.78	.292 00	.220 00	.8790 04	.168 01	.1379 01	.2486-01	.8478-03	.3219-03	.7273-03	.9308-02	.3480-02	.2735-08	.1959-07	.3121-05	.4236-09	.6194-08	.6131-06	.2537-05
.76	.258 00	.189 00	.9169 04	.170 01	.1496 01	.2492-01	.9198-03	.3219-03	.6106-03	.9169-02	.3475-02	.1655-08	.1557-07	.2560-05	.2293-09	.4112-08	.4933-06	.2106-05
.74	.227 00	.162 00	.9520 04	.180 01	.1639 01	.2497-01	.1003-02	.3219-03	.5069-03	.9009-02	.3470-02	.9731-09	.1220-07	.2110-05	.1196-09	.2661-08	.3922-06	.1736-05
.72	.199 00	.137 00	.9870 04	.190 01	.1804 01	.2502-01	.1098-02	.3219-03	.4158-03	.8826-02	.3463-02	.5549-09	.9415-08	.1705-05	.5996-10	.1675-08	.3077-06	.1409-05
.70	.173 00	.116 00	.1020 05	.200 01	.2000 01	.2507-01	.1206-02	.3219-03	.3368-03	.8616-02	.3454-02	.3063-09	.7141-08	.1361-05	.2883-10	.1024-08	.2379-06	.1131-05
.68	.152 00	.972-01	.1053 05	.208 01	.2234 01	.2511-01	.1334-02	.3219-03	.2690-03	.8378-02	.3439-02	.1632-09	.5316-08	.1070-05	.1325-10	.6056-09	.1806-06	.8956-06
.66	.130 00	.810-01	.1084 05	.219 01	.2514 01	.2515-01	.1479-02	.3219-03	.2118-03	.8110-02	.3419-02	.8377-10	.3875-08	.8291-06	.5797-11	.3462-09	.1346-06	.6966-06
.64	.115 00	.669-01	.1116 05	.240 01	.2855 01	.2518-01	.1643-02	.3219-03	.1641-03	.7810-02	.3390-02	.4126-10	.2756-08	.6315-06	.2407-11	.1905-09	.9822-07	.5362-06
.62	.945-01	.548-01	.1146 05	.251 01	.3274 01	.2522-01	.1830-02	.3219-03	.1250-03	.7476-02	.3351-02	.1947-10	.1912-08	.4722-06	.9447-12	.1006-09	.6997-07	.4042-06
.60	.792-01	.443-01	.1177 05	.263 01	.3796 01	.2526-01	.2040-02	.3219-03	.9346-04	.7107-02	.3300-02	.8756-11	.1266-08	.3459-06	.3466-12	.5079-10	.4842-07	.2966-06
.58	.658-01	.354-01	.1207 05	.276 01	.4455 01	.2531-01	.2275-02	.3219-03	.6847-04	.6703-02	.3233-02	.3736-11	.8307-09	.2476-06	.1203-12	.2459-10	.3246-07	.2162-06
.56	.540-01	.278-01	.1237 05	.290 01	.5298 01	.2538-01	.2538-02	.3219-03	.4905-04	.6265-02	.3150-02	.1507-11	.5264-09	.1731-06	.3833-13	.1109-10	.2099-07	.1526-06
.54	.437-01	.216-01	.1267 05	.304 01	.6394 01	.2542-01	.2823-02	.3219-03	.3427-04	.5795-02	.3048-02	.5766-12	.3170-09	.1175-06	.1137-13	.4743-11	.1304-07	.1042-06
.52	.348-01	.164-01	.1297 05	.319 01	.7840 01	.2549-01	.3136-02	.3219-03	.2327-04	.5290-02	.2925-02	.2014-12	.1821-09	.7733-07	.3064-14	.1894-11	.7726-08	.6979-07
.50	.273-01	.123-01	.1327 05	.335 01	.9777 01	.2558-01	.3472-02	.3219-03	.1531-04	.4760-02	.2782-02	.6571-13	.9916-10	.4909-07	.7446-15	.6997-12	.4347-08	.4464-07
.48	.210-01	.903-02	.1357 05	.351 01	.1241 02	.2565-01	.3830-02	.3219-03	.9706-05	.4210-02	.2618-02	.1962-13	.5062-10	.2992-07	.1611-15	.2366-12	.2304-08	.2766-07
.46	.159-01	.651-02	.1388 05	.369 01	.1605 02	.2574-01	.4204-02	.3219-03	.5897-05	.3645-02	.2434-02	.5296-14	.2430-10	.1739-07	.3046-16	.7222-13	.1141-08	.1627-07
.44	.119-01	.461-02	.1415 05	.387 01	.2108 02	.2584-01	.4585-02	.3219-03	.3407-05	.3076-02	.2232-02	.1273-14	.1072-10	.9566-08	.4941-17	.1956-13	.5227-09	.9054-08
.42	.872-02	.320-02	.1443 05	.406 01	.2812 02	.2595-01	.4977-02	.3219-03	.1856-05	.2520-02	.2013-02	.2675-15	.4306-11	.4933-08	.6669-18	.4626-14	.2191-09	.4716-08
.40	.633-02	.220-02	.1470 05	.425 01	.3804 02	.2607-01	.5359-02	.3219-03	.9416-06	.1986-02	.1763-02	.4605-16	.1550-11	.2356-08	.7323-19	.9242-15	.8266-10	.2274-08
.38	.455-02	.149-02	.1496 05	.445 01	.5198 02	.2619-01	.5724-02	.3219-03	.4391-06	.1494-02	.1546-02	.7177-17	.4901-12	.1026-08	.6234-20	.1519-15	.2764-10	.9992-09
.36	.327-02	.101-02	.1521 05	.465 01	.7130 02	.2631-01	.6059-02	.3219-03	.1846-06	.1061-02	.1308-02	.8612-18	.1329-12	.4005-09	.3930-21	.1973-16	.8145-11	.3925-09
.34	.235-02	.680-03	.1545 05	.486 01	.9772 02	.2642-01	.6355-02	.3219-03	.6869-07	.7019-03	.1075-02	.7900-19	.2996-13	.1369-09	.1729-22	.1930-17	.2027-11	.1349-09
.32	.170-02	.462-03	.1565 05	.506 01	.1331 03	.2653-01	.6602-02	.3219-03	.2200-07	.4268-03	.8554-03	.5362-20	.5436-14	.3909-10	.4930-24	.1344-18	.4107-12	.3946-10
.30	.124-02	.316-03	.1582 05	.526 01	.1790 03	.2663-01	.6799-02	.3219-03	.5684-08	.2345-03	.6547-03	.2497-21	.7592-15	.9005-11	.8375-26	.6216-20	.6622-13	.9337-11
.28	.919-03	.217-03	.1599 05	.547 01	.2409 03	.2672-01	.6947-02	.3219-03	.1207-08	.1143-03	.4789-03	.7336-23	.7752-16	.1636-11	.7372-28	.1736-21	.6452-14	.1629-11
.26	.682-03	.150-03	.1615 05	.569 01	.3215 03	.2680-01	.7055-02	.3219-03	.2096-09	.4629-04	.3319-03							
.24	.505-03	.102-03	.1629 05	.594 01	.4302 03	.2685-01	.7127-02	.3219-03	.2503-10	.1717-04	.2152-03							
.22	.378-03	.688-04	.1643 05	.622 01	.5811 03	.2690-01	.7177-02	.3219-03	.1960-11	.4919-05	.1265-03							
.20	.280-03	.452-04	.1656 05	.655 01	.7977 03	.2693-01	.7209-02	.3219-03	.9202-13	.1069-05	.6901-04							
.18	.207-03	.288-04	.1669 05	.693 01	.1120 04	.2695-01	.7227-02	.3219-03	.2104-14	.1606-06	.3219-04							
.16	.150-03	.175-04	.1682 05	.738 01	.1620 04	.2696-01	.7237-02	.3219-03	.1815-16	.1460-07	.1238-04							
.14	.858-04	.101-04	.1695 05	.791 01	.2436 04	.2696-01	.7242-02	.3219-03	.3660-19	.6436-09	.3621-05							
.12	.559-04	.548-05	.1705 05	.856 01	.3833 04	.2696-01	.7243-02	.3219-03	.1022-22	.9574-11	.7026-06							
.10	.316-04	.267-05	.1716 05	.942 01	.6525 04	.2696-01	.7244-02	.3219-03	.9406-28	.2493-13	.7085-07							
.08	.160-04	.114-05	.1727 05	.106 02	.1210 05	.2696-01	.7244-02	.3219-03	.2424-35	.3049-17	.2278-08							
.06	.771-05	.391-06	.1736 05	.122 02	.2640 05	.2696-01	.7244-02	.3219-03		.8092-24	.7499-11							

Table 16. EQUILIBRIUM AIRFLOW EXPANSION

$T_o' = 8000°K$, $p_o' = 1000$ atm., $\rho_o' = 3.722 \times 10^{-2}$ gm/cm^3,

$H_o = 6.289$, $(\rho u)_* = .7105$ at $T = .910$, $\bar{\mu}_o = 24.43$ gm/mole

$\ell = 0.1$

T	ρ	P	u' (ft/sec.)	M	A
.844	.400 00	.333 00	.5101 04	.141 01	.1134 01
.84	.394 00	.326 00	.5143 04	.141 01	.1143 01
.82	.362 00	.293 00	.5352 04	.149 01	.1193 01
.80	.333 00	.263 00	.5553 04	.156 01	.1251 01
.78	.306 00	.235 00	.5747 04	.164 01	.1317 01
.76	.280 00	.210 00	.5934 04	.171 01	.1394 01
.74	.255 00	.186 00	.6116 04	.179 01	.1481 01
.72	.233 00	.165 00	.6292 04	.186 01	.1580 01
.70	.212 00	.146 00	.6463 04	.194 01	.1692 01
.68	.192 00	.129 00	.6629 04	.202 01	.1820 01
.66	.173 00	.113 00	.6791 04	.210 01	.1965 01
.64	.156 00	.986-01	.6949 04	.218 01	.2131 01
.62	.140 00	.858-01	.7104 04	.226 01	.2320 01
.60	.126 00	.744-01	.7254 04	.235 01	.2536 01
.58	.112 00	.642-01	.7402 04	.244 01	.2785 01
.56	.998-01	.551-01	.7546 04	.253 01	.3072 01
.54	.884-01	.471-01	.7687 04	.262 01	.3405 01
.52	.780-01	.400-01	.7826 04	.272 01	.3791 01
.50	.585-01	.337-01	.7962 04	.282 01	.4244 01
.48	.598-01	.283-01	.8095 04	.293 01	.4776 01
.46	.520-01	.236-01	.8225 04	.304 01	.5406 01
.44	.450-01	.195-01	.8353 04	.315 01	.6156 01
.42	.387-01	.160-01	.8478 04	.327 01	.7056 01
.40	.330-01	.130-01	.8601 04	.340 01	.8144 01
.38	.280-01	.105-01	.8722 04	.353 01	.9469 01
.36	.236-01	.837-02	.8840 04	.367 01	.1110 02
.34	.197-01	.660-02	.8957 04	.383 01	.1312 02
.32	.163-01	.514-02	.9070 04	.399 01	.1567 02
.30	.133-01	.394-02	.9182 04	.417 01	.1890 02
.28	.108-01	.298-02	.9291 04	.436 01	.2307 02
.26	.864-02	.221-02	.9397 04	.456 01	.2851 02
.24	.681-02	.161-02	.9502 04	.479 01	.3575 02
.22	.529-02	.115-02	.9603 04	.505 01	.4558 02
.20	.403-02	.794-03	.9702 04	.534 01	.5922 02
.18	.300-02	.532-03	.9799 04	.567 01	.7871 02
.16	.218-02	.343-03	.9893 04	.605 01	.1075 03
.14	.152-02	.210-03	.9985 04	.650 01	.1521 03
.12	.102-02	.121-03	.1007 05	.707 01	.2254 03
.10	.639-03	.629-04	.1016 05	.779 01	.3565 03
.09	.489-03	.434-04	.1020 05	.824 01	.4639 03
.08	.363-03	.286-04	.1025 05	.877 01	.6223 03
.07	.25[illegible]-03	.179-04	.1029 05	.941 01	.8675 03
.06	.176-03	.104-04	.1033 05	.102 02	.1273 04
.05	.111-03	.548-05	.1037 05	.112 02	.2005 04
.04	.635-04	.250-05	.1042 05	.126 02	.3500 04
.03	.308-04	.910-06	.1046 05	.146 02	.7184 04
.02	.111-04	.219-06	.1050 05	.180 02	.1983 05
.01	.195-05	.199-07	.1054 05	.252 02	.1128 06

$\ell = 1.0$

T	ρ	P	u' (ft/sec.)	M	A
.73	.196 00	.140 00	.6560 04	.196 01	.1795 01
.72	.187 00	.132 00	.6643 04	.198 01	.1858 01
.70	.170 00	.116 00	.6805 04	.205 01	.1998 01
.68	.154 00	.102 00	.6963 04	.213 01	.2156 01
.66	.139 00	.898-01	.7117 04	.221 01	.2335 01
.64	.125 00	.784-01	.7268 04	.229 01	.2540 01
.62	.113 00	.682-01	.7415 04	.238 01	.2773 01
.60	.101 00	.591-01	.7560 04	.246 01	.3040 01
.58	.898-01	.509-01	.7701 04	.255 01	.3347 01
.56	.797-01	.437-01	.7840 04	.264 01	.3701 01
.54	.706-01	.373-01	.7976 04	.274 01	.4111 01
.52	.622-01	.316-01	.8109 04	.283 01	.4589 01
.50	.545-01	.267-01	.8240 04	.293 01	.5149 01
.48	.476-01	.223-01	.8368 04	.304 01	.5809 01
.46	.413-01	.186-01	.8494 04	.315 01	.6590 01
.44	.357-01	.154-01	.8618 04	.327 01	.7521 01
.42	.306-01	.126-01	.8740 04	.339 01	.8640 01
.40	.261-01	.102-01	.8859 04	.352 01	.9994 01
.38	.221-01	.822-02	.8976 04	.365 01	.1165 02
.36	.186-01	.655-02	.9091 04	.380 01	.1368 02
.34	.155-01	.515-02	.9204 04	.395 01	.1622 02
.32	.128-01	.400-02	.9314 04	.412 01	.1941 02
.30	.105-01	.307-02	.9422 04	.430 01	.2347 02
.28	.846-02	.232-02	.9529 04	.449 01	.2871 02
.26	.675-02	.172-02	.9632 04	.470 01	.3557 02
.24	.531-02	.125-02	.9734 04	.494 01	.4472 02
.22	.412-02	.885-03	.9833 04	.520 01	.5717 02
.20	.313-02	.612-03	.9930 04	.549 01	.7448 02
.18	.233-02	.409-03	.1002 05	.583 01	.9927 02
.16	.168-02	.263-03	.1012 05	.622 01	.1360 03
.14	.117-02	.161-03	.1021 05	.668 01	.1930 03
.12	.783-03	.919-04	.1029 05	.726 01	.2870 03
.10	.489-03	.478-04	.1038 05	.800 01	.4558 03
.09	.374-03	.329-04	.1042 05	.845 01	.5942 03
.08	.277-03	.217-04	.1046 05	.900 01	.7989 03
.07	.197-03	.135-04	.1050 05	.965 01	.1117 04
.06	.134-03	.783-05	.1054 05	.105 02	.1643 04
.05	.842-04	.411-05	.1059 05	.115 02	.2597 04
.04	.478-04	.187-05	.1063 05	.129 02	.4551 04
.03	.231-04	.677-06	.1067 05	.150 02	.9388 04
.02	.828-05	.162-06	.1071 05	.184 02	.2610 05
.01	.143-05	.142-07	.1075 05	.260 02	.1502 06

$\ell = 10$

T	ρ	P	u' (ft/sec.)	M	A
.626	.985-01	.601-01	.7545 04	.243 01	.3113 01
.62	.953-01	.576-01	.7587 04	.244 01	.3199 01
.60	.852-01	.498-01	.7729 04	.252 01	.3512 01
.58	.760-01	.429-01	.7867 04	.261 01	.3871 01
.56	.675-01	.368-01	.8003 04	.270 01	.4286 01
.54	.597-01	.314-01	.8136 04	.280 01	.4767 01
.52	.525-01	.266-01	.8266 04	.289 01	.5328 01
.50	.461-01	.224-01	.8395 04	.300 01	.5985 01
.48	.402-01	.188-01	.8521 04	.310 01	.6758 01
.46	.349-01	.156-01	.8644 04	.321 01	.7675 01
.44	.301-01	.129-01	.8766 04	.333 01	.8770 01
.42	.258-01	.106-01	.8885 04	.345 01	.1009 02
.40	.220-01	.857-02	.9003 04	.358 01	.1168 02
38	.186-01	.689-02	.9118 04	.372 01	.1363 02
.36	.156-01	.548-02	.9231 04	.387 01	.1603 02
.34	.130-01	.431-02	.9342 04	.402 01	.1901 02
.32	.107-01	.335-02	.9451 04	.419 01	.2278 02
.30	.878-02	.257-02	.9557 04	.437 01	.2757 02
.28	.709-02	.193-02	.9662 04	.456 01	.3377 02
.26	.566-02	.143-02	.9764 04	.478 01	.4189 02
.24	.445-02	.104-02	.9864 04	.501 01	.5273 02
.22	.344-02	.738-03	.9962 04	.528 01	.6748 02
.20	.261-02	.509-03	.1006 05	.557 01	.8803 02
.18	.194-02	.340-03	.1015 05	.591 01	.1175 03
.16	.140-02	.218-03	.1024 05	.631 01	.1612 03
.14	.978-03	.133-03	.1033 05	.678 01	.2291 03
.12	.651-03	.761-04	.1042 05	.736 01	.3412 03
.10	.406-03	.396-04	.1050 05	.811 01	.5427 03
.09	.310-03	.272-04	.1054 05	.857 01	.7082 03
.08	.229-03	.179-04	.1058 05	.912 01	.9532 03
.07	.163-03	.111-04	.1062 05	.978 01	.1334 04
.06	.110-03	.645-05	.1066 05	.106 02	.1965 04
.05	.695-04	.339-05	.1070 05	.117 02	.3110 04
.04	.394-04	.154-05	.1075 05	.131 02	.5459 04
.03	.190-04	.555-06	.1079 05	.152 02	.1129 05
.02	.679-05	.131-06	.1083 05	.187 02	.3148 05
.01	.117-05	.113-07	.1087 05	.266 02	.1822 06

Table 17a. EXPANSION AFTER FREEZING - WEDGE NOZZLE

$T_o' = 4000°K$, $p_o' = 100$ atm.

ℓ = 0.1

T	ρ	P	u' (ft/sec.)	M	A
.88	.502 00	.437 00	.4517 04	.122 01	.1020 01
.86	.464 00	.394 00	.4754 04	.129 01	.1049 01
.84	.428 00	.356 00	.4980 04	.136 01	.1085 01
.82	.395 00	.320 00	.5195 04	.144 01	.1129 01
.80	.363 00	.287 00	.5402 04	.152 01	.1181 01
.78	.333 00	.257 00	.5601 04	.159 01	.1241 01
.76	.305 00	.229 00	.5793 04	.167 01	.1310 01
.74	.278 00	.204 00	.5979 04	.174 01	.1390 01
.72	.254 00	.181 00	.6159 04	.182 01	.1481 01
.70	.231 00	.160 00	.6333 04	.190 01	.1584 01
.68	.209 00	.141 00	.6503 04	.198 01	.1701 01
.66	.189 00	.123 00	.6668 04	.206 01	.1834 01
.64	.171 00	.108 00	.6829 04	.214 01	.1987 01
.62	.153 00	.939-01	.6986 04	.222 01	.2160 01
.60	.137 00	.814-01	.7140 04	.231 01	.2359 01
.58	.123 00	.703-01	.7290 04	.240 01	.2588 01
.56	.109 00	.604-01	.7436 04	.249 01	.2852 01
.54	.967-01	.516-01	.7580 04	.258 01	.3158 01
.52	.853-01	.438-01	.7720 04	.268 01	.3514 01
.50	.749-01	.370-01	.7857 04	.278 01	.3929 01
.48	.655-01	.311-01	.7992 04	.288 01	.4419 01
.46	.570-01	.259-01	.8124 04	.299 01	.4997 01
.44	.493-01	.214-01	.8254 04	.311 01	.5686 01
.42	.424-01	.176-01	.8381 04	.323 01	.6511 01
.40	.362-01	.143-01	.8505 04	.335 01	.7509 01
.38	.307-01	.115-01	.8627 04	.349 01	.8724 01
.36	.259-01	.921-02	.8747 04	.363 01	.1022 02
.34	.216-01	.727-02	.8865 04	.378 01	.1207 02
.32	.179-01	.566-02	.8979 04	.394 01	.1440 02
.30	.147-01	.435-02	.9092 04	.412 01	.1736 02
.28	.119-01	.329-02	.9202 04	.431 01	.2116 02
.26	.951-02	.244-02	.9310 04	.451 01	.2614 02
.24	.750-02	.178-02	.9415 04	.474 01	.3275 02
.22	.583-02	.127-02	.9518 04	.500 01	.4171 02
.20	.444-02	.878-03	.9618 04	.528 01	.5414 02
.18	.331-02	.589-03	.9715 04	.561 01	.7189 02
.16	.240-02	.380-03	.9810 04	.599 01	.9810 02
.14	.169-02	.233-03	.9903 04	.644 01	.1386 03
.12	.113-02	.134-03	.9993 04	.700 01	.2052 03
.10	.708-03	.700-04	.1008 05	.772 01	.3242 03
.09	.542-03	.482-04	.1012 05	.816 01	.4216 03
.08	.403-03	.318-04	.1017 05	.868 01	.5651 03
.07	.288-03	.199-04	.1021 05	.932 01	.7872 03
.06	.195-03	.116-04	.1025 05	.101 02	.1154 04
.05	.124-03	.611-05	.1030 05	.111 02	.1816 04
.04	.707-04	.279-05	.1034 05	.125 02	.3166 04
.03	.343-04	.102-05	.1038 05	.145 02	.6489 04
.02	.124-04	.245-06	.1042 05	.178 02	.1787 05
.01	.218-05	.227-07	.1046 05	.249 02	.1013 06

ℓ = 1.0

T	ρ	P	u' (ft/sec.)	M	A
.753	.227 00	.167 00	.6304 04	.186 01	.1617 01
.74	.214 00	.155 00	.6415 04	.188 01	.1687 01
.72	.195 00	.137 00	.6583 04	.196 01	.1805 01
.70	.177 00	.121 00	.6746 04	.203 01	.1940 01
.68	.160 00	.107 00	.6906 04	.211 01	.2092 01
.66	.145 00	.935-01	.7061 04	.219 01	.2265 01
.64	.130 00	.816-01	.7213 04	.227 01	.2462 01
.62	.117 00	.710-01	.7362 04	.236 01	.2687 01
.60	.105 00	.615-01	.7508 04	.244 01	.2944 01
.58	.934-01	.530-01	.7650 04	.253 01	.3240 01
.56	.829-01	.455-01	.7790 04	.262 01	.3581 01
.54	.734-01	.388-01	.7926 04	.272 01	.3977 01
.52	.647-01	.329-01	.8061 04	.281 01	.4438 01
.50	.567-01	.278-01	.8192 04	.292 01	.4977 01
.48	.495-01	.233-01	.8321 04	.302 01	.5613 01
.46	.430-01	.194-01	.8448 04	.313 01	.6365 01
.44	.372-01	.160-01	.8573 04	.325 01	.7262 01
.42	.319-01	.131-01	.8695 04	.337 01	.8340 01
.40	.272-01	.107-01	.8815 04	.350 01	.9643 01
.38	.231-01	.858-02	.8932 04	.363 01	.1123 02
.36	.194-01	.683-02	.9048 04	.378 01	.1319 02
.34	.162-01	.538-02	.9161 04	.393 01	.1563 02
.32	.133-01	.418-02	.9272 04	.410 01	.1870 02
.30	.109-01	.320-02	.9381 04	.427 01	.2260 02
.28	.882-02	.242-02	.9488 04	.447 01	.2764 02
.26	.705-02	.179-02	.9592 04	.468 01	.3424 02
.24	.555-02	.130-02	.9694 04	.491 01	.4303 02
.22	.430-02	.925-03	.9793 04	.517 01	.5498 02
.20	.327-02	.640-03	.9890 04	.546 01	.7160 02
.18	.243-02	.428-03	.9985 04	.580 01	.9538 02
.16	.176-02	.275-03	.1008 05	.619 01	.1306 03
.14	.123-02	.168-03	.1017 05	.665 01	.1853 03
.12	.819-03	.962-04	.1025 05	.723 01	.2754 03
.10	.512-03	.501-04	.1034 05	.796 01	.4371 03
.09	.391-03	.345-04	.1038 05	.842 01	.5697 03
.08	.290-03	.227-04	.1042 05	.896 01	.7656 03
.07	.207-03	.142-04	.1047 05	.961 01	.1070 04
.06	.140-03	.822-05	.1051 05	.104 02	.1574 04
.05	.882-04	.432-05	.1055 05	.115 02	.2486 04
.04	.502-04	.197-05	.1059 05	.129 02	.4353 04
.03	.243-04	.711-06	.1063 05	.149 02	.8974 04
.02	.870-05	.171-06	.1067 05	.183 02	.2492 05
.01	.151-05	.142-07	.1071 05	.263 02	.1432 06

ℓ = 10

T	ρ	P	u' (ft/sec.)	M	A
.665	.127 00	.827-01	.7202 04	.225 01	.2520 01
.66	.124 00	.800-01	.7239 04	.225 01	.2572 01
.64	.112 00	.698-01	.7368 04	.233 01	.2800 01
.62	.100 00	.607-01	.7533 04	.242 01	.3060 01
.60	.898-01	.525-01	.7675 04	.250 01	.3358 01
.58	.800-01	.453-01	.7814 04	.259 01	.3700 01
.56	.711-01	.388-01	.7951 04	.268 01	.4095 01
.54	.629-01	.331-01	.8085 04	.278 01	.4553 01
.52	.554-01	.281-01	.8216 04	.287 01	.5086 01
.50	.485-01	.237-01	.8345 04	.298 01	.5711 01
.48	.424-01	.198-01	.8472 04	.308 01	.6448 01
.46	.368-01	.165-01	.8597 04	.319 01	.7320 01
.44	.317-01	.136-01	.8719 04	.331 01	.8361 01
.42	.272-01	.112-01	.8839 04	.343 01	.9612 01
.40	.232-01	.906-02	.8957 04	.356 01	.1113 02
.38	.197-01	.728-02	.9073 04	.370 01	.1298 02
.36	.165-01	.580-02	.9186 04	.384 01	.1526 02
.34	.138-01	.456-02	.9298 04	.400 01	.1810 02
.32	.113-01	.354-02	.9407 04	.417 01	.2167 02
.30	.927-02	.271-02	.9514 04	.435 01	.2623 02
.28	.749-02	.205-02	.9619 04	.454 01	.3211 02
.26	.598-02	.152-02	.9722 04	.475 01	.3982 02
.24	.470-02	.110-02	.9823 04	.499 01	.5010 02
.22	.364-02	.781-03	.9921 04	.525 01	.6409 02
.20	.276-02	.539-03	.1002 05	.555 01	.8358 02
.18	.205-02	.360-03	.1011 05	.588 01	.1115 03
.16	.148-02	.231-03	.1020 05	.628 01	.1529 03
.14	.104-02	.141-03	.1029 05	.675 01	.2172 03
.12	.690-03	.807-04	.1038 05	.733 01	.3233 03
.10	.430-03	.420-04	.1046 05	.807 01	.5141 03
.09	.328-03	.288-04	.1050 05	.853 01	.6707 03
.08	.243-03	.190-04	.1054 05	.908 01	.9024 03
.07	.173-03	.118-04	.1058 05	.974 01	.1262 04
.06	.117-03	.685-05	.1063 05	.106 02	.1859 04
.05	.738-04	.360-05	.1067 05	.116 02	.2941 04
.04	.419-04	.163-05	.1071 05	.130 02	.5159 04
.03	.202-04	.592-06	.1075 05	.151 02	.1066 05
.02	.722-05	.139-06	.1079 05	.186 02	.2970 05
.01	.125-05	.113-07	.1083 05	.270 02	.1717 06

Table 17b. EXPANSION AFTER FREEZING - HYPERBOLIC NOZZLE

$T_o' = 4000°K$, $p_o' = 100$ atm.

$\ell = 0.1$

T	ρ	P	u' (ft/sec.)	M	A
.77	.282 00	.214 00	.5865 04	.170 01	.1396 01
.76	.270 00	.202 00	.5958 04	.172 01	.1437 01
.74	.246 00	.180 00	.6138 04	.179 01	.1529 01
.72	.224 00	.159 00	.6313 04	.187 01	.1633 01
.70	.203 00	.141 00	.6484 04	.195 01	.1751 01
.68	.184 00	.124 00	.5649 04	.203 01	.1886 01
.66	.166 00	.108 00	.6811 04	.211 01	.2039 01
.64	.150 00	.946-01	.6968 04	.219 01	.2213 01
.62	.134 00	.823-01	.7122 04	.227 01	.2413 01
.60	.120 00	.712-01	.7272 04	.236 01	.2641 01
.58	.107 00	.614-01	.7419 04	.244 01	.2904 01
.56	.952-01	.526-01	.7563 04	.254 01	.3207 01
.54	.842-01	.449-01	.7704 04	.263 01	.3559 01
.52	.742-01	.381-01	.7842 04	.273 01	.3969 01
.50	.651-01	.321-01	.7977 04	.283 01	.4449 01
.48	.568-01	.269-01	.8109 04	.293 01	.5014 01
.46	.493-01	.224-01	.8239 04	.304 01	.5684 01
.44	.426-01	.185-01	.8367 04	.316 01	.6483 01
.42	.365-01	.151-01	.8492 04	.328 01	.7442 01
.40	.311-01	.123-01	.8615 04	.340 01	.8603 01
.38	.264-01	.990-02	.8735 04	.354 01	.1002 02
.36	.222-01	.788-02	.8853 04	.368 01	.1177 02
.34	.185-01	.620-02	.8969 04	.383 01	.1394 02
.32	.152-01	.482-02	.9082 04	.400 01	.1667 02
.30	.125-01	.369-02	.9193 04	.417 01	.2016 02
.28	.101-01	.278-02	.9302 04	.436 01	.2465 02
.26	.804-02	.206-02	.9408 04	.457 01	.3054 02
.24	.632-02	.150-02	.9512 04	.480 01	.3838 02
.22	.490-02	.106-02	.9613 04	.506 01	.4905 02
.20	.372-02	.735-03	.9712 04	.534 01	.6390 02
.18	.276-02	.491-03	.9808 04	.567 01	.8515 02
.16	.200-02	.316-03	.9902 04	.606 01	.1167 03
.14	.140-02	.193-03	.9993 04	.651 01	.1656 03
.12	.930-03	.110-03	.1008 05	.708 01	.2462 03
.10	.561-03	.573-04	.1017 05	.780 01	.3910 03
.09	.443-03	.394-04	.1021 05	.824 01	.5098 03
.08	.326-03	.259-04	.1026 05	.878 01	.6854 03
.07	.234-03	.162-04	.1030 05	.941 01	.9580 03
.06	.158-03	.938-05	.1034 05	.102 02	.1410 04
.05	.998-04	.492-05	.1038 05	.112 02	.2229 04
.04	.567-04	.224-05	.1042 05	.126 02	.3907 04
.03	.274-04	.811-06	.1046 05	.146 02	.8064 04
.02	.980-05	.193-06	.1051 05	.180 02	.2243 05
.01	.169-05	.172-07	.1055 05	.253 02	.1294 06

$\ell = 1.0$

T	ρ	P	u' (ft/sec.)	M	A
.651	.137 00	.878-01	.7067 04	.223 01	.2384 01
.64	.129 00	.815-01	.7151 04	.225 01	.2498 01
.62	.116 00	.708-01	.7301 04	.233 01	.2726 01
.60	.104 00	.613-01	.7448 04	.242 01	.2989 01
.58	.924-01	.528-01	.7591 04	.251 01	.3290 01
.56	.821-01	.453-01	.7732 04	.260 01	.3638 01
.54	.726-01	.386-01	.7869 04	.269 01	.4042 01
.52	.639-01	.327-01	.8004 04	.279 01	.4513 01
.50	.560-01	.276-01	.8137 04	.289 01	.5064 01
.48	.489-01	.231-01	.8267 04	.299 01	.5713 01
.46	.424-01	.192-01	.8394 04	.310 01	.6483 01
.44	.366-01	.159-01	.8519 04	.322 01	.7401 01
.42	.314-01	.130-01	.8642 04	.334 01	.8505 01
.40	.268-01	.105-01	.8763 04	.347 01	.9842 01
.38	.227-01	.848-02	.8881 04	.360 01	.1147 02
.36	.190-01	.674-02	.8997 04	.375 01	.1349 02
.34	.158-01	.530-02	.9111 04	.390 01	.1599 02
.32	.131-01	.412-02	.9222 04	.407 01	.1915 02
.30	.107-01	.315-02	.9332 04	.424 01	.2317 02
.28	.862-02	.238-02	.9439 04	.443 01	.2836 02
.26	.688-02	.176-02	.9544 04	.465 01	.3516 02
.24	.541-02	.128-02	.9646 04	.488 01	.4424 02
.22	.419-02	.907-03	.9746 04	.513 01	.5660 02
.20	.318-02	.626-03	.9843 04	.543 01	.7380 02
.18	.236-02	.418-03	.9938 04	.576 01	.9846 02
.16	.170-02	.269-03	.1003 05	.614 01	.1350 03
.14	.119-02	.164-03	.1012 05	.661 01	.1919 03
.12	.792-03	.935-04	.1021 05	.718 01	.2856 03
.10	.494-03	.486-04	.1029 05	.791 01	.4542 03
.09	.377-03	.334-04	.1034 05	.836 01	.5927 03
.08	.279-03	.220-04	.1038 05	.890 01	.7976 03
.07	.199-03	.137-04	.1042 05	.954 01	.1116 04
.06	.134-03	.793-05	.1046 05	.103 02	.1644 04
.05	.845-04	.416-05	.1050 05	.114 02	.2602 04
.04	.479-04	.189-05	.1054 05	.128 02	.4566 04
.03	.231-04	.682-06	.1059 05	.148 02	.9440 04
.02	.825-05	.161-06	.1063 05	.182 02	.2632 05
.01	.142-05	.143-07	.1067 05	.257 02	.1524 06

$\ell = 10$

T	ρ	P	u' (ft/sec.)	M	A
.558	.740-01	.406-01	.7826 04	.265 01	.3986 01
.54	.664-01	.353-01	.7947 04	.272 01	.4372 01
.52	.585-01	.299-01	.8081 04	.282 01	.4884 01
.50	.513-01	.252-01	.8212 04	.292 01	.5482 01
.48	.447-01	.211-01	.8341 04	.302 01	.6188 01
.46	.388-01	.176-01	.8467 04	.313 01	.7025 01
.44	.335-01	.145-01	.8591 04	.325 01	[illegible] 01
.42	.287-01	.119-01	.8713 04	.337 01	.9224 01
.40	.245-01	.963-02	.8832 04	.350 01	.1066 02
.38	.207-01	.774-02	.8950 04	.363 01	.1245 02
.36	.174-01	.616-02	.9065 04	.378 01	.1464 02
.34	.145-01	.485-02	.9178 04	.393 01	.1747 02
.32	.119-01	.376-02	.9289 04	.410 01	.2080 02
.30	.976-02	.288-02	.9397 04	.427 01	.2517 02
.28	.788-02	.217-02	.9503 04	.447 01	.3082 02
.26	.628-02	.161-02	.9607 04	.468 01	.3823 02
.24	.494-02	.117-02	.9709 04	.491 01	.4812 02
.22	.382-02	.827-03	.9808 04	.517 01	.6158 02
.20	.290-02	.571-03	.9905 04	.546 01	.8033 02
.18	.215-02	.381-03	.9999 04	.580 01	.1072 03
.16	.156-02	.245-03	.1009 05	.618 01	.1471 03
.14	.108-02	.149-03	.1018 05	.665 01	.2091 03
.12	.722-03	.852-04	.1027 05	.722 01	.3114 03
.10	.450-03	.443-04	.1035 05	.796 01	.4954 03
.09	.343-03	.304-04	.1040 05	.841 01	.6466 03
.08	.254-03	.200-04	.1044 05	.895 01	.8704 03
.07	.181-03	.125-04	.1048 05	.960 01	.1218 04
.06	.122-03	.722-05	.1052 05	.104 02	.1795 04
.05	.769-04	.378-05	.1056 05	.114 02	.2842 04
.04	.436-04	.172-05	.1060 05	.128 02	.4940 04
.03	.210-04	.621-06	.1064 05	.149 02	.1032 05
.02	.750-05	.147-06	.1068 05	.183 02	.2880 05
.01	.129-05	.115-07	.1072 05	.268 02	.1669 06

Table 18a. EXPANSION AFTER FREEZING - WEDGE NOZZLE

$T_o' = 4000°K$, $p_o' = 300$ atm.

$\ell = 0.1$

T	ρ	P	u' (ft/sec.)	M	A
.776	.293 00	.225 00	.5790 04	.167 01	.1361 01
.76	.273 00	.205 00	.5939 04	.171 01	.1425 01
.74	.249 00	.182 00	.6120 04	.179 01	.1516 01
.72	.227 00	.161 00	.6296 04	.186 01	.1619 01
.70	.206 00	.142 00	.6467 04	.194 01	.1736 01
.68	.186 00	.125 00	.6633 04	.202 01	.1868 01
.66	.168 00	.110 00	.6794 04	.210 01	.2020 01
.64	.151 00	.958-01	.6952 04	.218 01	.2192 01
.62	.136 00	.833-01	.7106 04	.227 01	.2389 01
.60	.122 00	.721-01	.7257 04	.235 01	.2615 01
.58	.108 00	.621-01	.7404 04	.244 01	.2875 01
.56	.963-01	.533-01	.7548 04	.253 01	.3175 01
.54	.[illegible]2-01	.455-01	.7689 04	.262 01	.3522 01
.52	.751-01	.386-01	.7828 04	.272 01	.3927 01
.50	.659-01	.325-01	.7953 04	.282 01	.4402 01
.48	.575-01	.273-01	.8096 04	.293 01	.4960 01
.46	.499-01	.227-01	.8226 04	.304 01	.5622 01
.44	.[illegible]31-01	.187-01	.8354 04	.315 01	.6412 01
.42	.370-01	.153-01	.8479 04	.327 01	.7360 01
.40	.315-01	.125-01	.8602 04	.340 01	.8507 01
.38	.267-01	.100-01	.8722 04	.353 01	.9907 01
.35	.224-01	.798-02	.8841 04	.367 01	.1163 02
.34	.187-01	.628-02	.8956 04	.383 01	.1378 02
.32	.154-01	.488-02	.9070 04	.399 01	.1648 02
.30	.126-01	.374-02	.9181 04	.417 01	.1992 02
.28	.102-01	.282-02	.9290 04	.436 01	.2435 02
.26	.814-02	.209-02	.9397 04	.456 01	.3016 02
.24	.641-02	.152-02	.9501 04	.479 01	.3791 02
.22	.496-02	.108-02	.9602 04	.505 01	.4844 02
.20	.377-02	.745-03	.9701 04	.534 01	.6309 02
.18	.280-02	.498-03	.9797 04	.566 01	.8406 02
.16	.203-02	.320-03	.9891 04	.605 01	.1152 03
.14	.142-02	.196-03	.9983 04	.650 01	.1634 03
.12	.944-03	.112-03	.1007 05	.707 01	.2429 03
.10	.589-03	.582-04	.1016 05	.779 01	.3856 03
.09	.450-03	.400-04	.1020 05	.823 01	.5027 03
.08	.333-03	.264-04	.1024 05	.876 01	.6758 03
.07	.238-03	.164-04	.1029 05	.940 01	.9444 03
.06	.161-03	.953-05	.1033 05	.102 02	.1390 04
.05	.101-03	.500-05	.1037 05	.112 02	.2197 04
.04	.576-04	.228-05	.1041 05	.126 02	.3849 04
.03	.278-04	.825-06	.1045 05	.146 02	.7941 04
.02	.996-05	.196-06	.1050 05	.180 02	.2208 05
.01	.172-05	.172-07	.1054 05	.254 02	.1272 06

$\ell = 1.0$

T	ρ	P	u' (ft/sec.)	M	A
.684	.167 00	.113 00	.6766 04	.208 01	.2037 01
.68	.164 00	.110 00	.6798 04	.207 01	.2069 01
.66	.148 00	.964-01	.6956 04	.215 01	.2239 01
.64	.133 00	.841-01	.7110 04	.223 01	.2434 01
.62	.120 00	.731-01	.7261 04	.232 01	.2656 01
.60	.107 00	.633-01	.7408 04	.240 01	.2910 01
.58	.954-01	.545-01	.7552 04	.249 01	.3203 01
.56	.847-01	.468-01	.7694 04	.258 01	.3541 01
.54	.749-01	.399-01	.7832 04	.268 01	.3933 01
.52	.660-01	.338-01	.7968 04	.277 01	.4390 01
.50	.579-01	.285-01	.8101 04	.287 01	.4925 01
.48	.505-01	.239-01	.8231 04	.298 01	.5555 01
.46	.438-01	.199-01	.8359 04	.309 01	.6302 01
.44	.378-01	.164-01	.8485 04	.320 01	.7193 01
.42	.325-01	.134-01	.8608 04	.333 01	.8264 01
.40	.277-01	.109-01	.8729 04	.345 01	.9561 01
.38	.234-01	.877-02	.8848 04	.359 01	.1114 02
.36	.197-01	.697-02	.8964 04	.373 01	.1310 02
.34	.164-01	.549-02	.9079 04	.389 01	.1553 02
.32	.135-01	.426-02	.9191 04	.405 01	.1858 02
.30	.110-01	.326-02	.9300 04	.423 01	.2248 02
.28	.892-02	.246-02	.9408 04	.442 01	.2751 02
.26	.711-02	.182-02	.9513 04	.463 01	.3411 02
.24	.560-02	.132-02	.9616 04	.486 01	.4290 02
.22	.433-02	.939-03	.9716 04	.512 01	.5487 02
.20	.329-02	.648-03	.9814 04	.541 01	.7154 02
.18	.244-02	.433-03	.9909 04	.574 01	.9541 02
.16	.176-02	.278-03	.1000 05	.612 01	.1308 03
.14	.123-02	.170-03	.1009 05	.659 01	.1858 03
.12	.820-03	.969-04	.1018 05	.715 01	.2766 03
.10	.511-03	.504-04	.1027 05	.788 01	.4397 03
.09	.390-03	.346-04	.1031 05	.833 01	.5736 03
.08	.289-03	.228-04	.1035 05	.887 01	.7717 03
.07	.206-03	.142-04	.1039 05	.951 01	.1079 04
.06	.139-03	.823-05	.1043 05	.103 02	.1590 04
.05	.876-04	.432-05	.1048 05	.113 02	.2515 04
.04	.497-04	.196-05	.1052 05	.127 02	.4413 04
.03	.240-04	.708-06	.1056 05	.148 02	.9120 04
.02	.857-05	.170-06	.1060 05	.181 02	.2541 05
.01	.148-05	.143-07	.1064 05	.259 02	.1470 06

$\ell = 10$

T	ρ	P	u' (ft/sec.)	M	A
.597	.960-01	.564-01	.7523 04	.247 01	.3197 01
.58	.870-01	.497-01	.7643 04	.252 01	.3471 01
.56	.773-01	.426-01	.7783 04	.261 01	.3839 01
.54	.683-01	.363-01	.7920 04	.271 01	.4267 01
.52	.602-01	.308-01	.8054 04	.281 01	.4766 01
.50	.527-01	.259-01	.8185 04	.291 01	.5348 01
.48	.460-01	.217-01	.8315 04	.301 01	.6036 01
.46	.399-01	.181-01	.8441 04	.312 01	.6852 01
.44	.344-01	.149-01	.8566 04	.324 01	.7823 01
.42	.295-01	.122-01	.8688 04	.336 01	.8942 01
.40	.252-01	.991-02	.8808 04	.349 01	.1041 02
.38	.213-01	.797-02	.8926 04	.362 01	.1214 02
.36	.179-01	.634-02	.9041 04	.377 01	.1427 02
.34	.149-01	.499-02	.9154 04	.392 01	.1697 02
.32	.123-01	.387-02	.9265 04	.409 01	.2027 02
.30	.100-01	.296-02	.9374 04	.426 01	.2453 02
.28	.811-02	.223-02	.9481 04	.446 01	.3003 02
.26	.647-02	.165-02	.9585 04	.467 01	.3725 02
.24	.508-02	.120-02	.9687 04	.490 01	.4687 02
.22	.393-02	.852-03	.9786 04	.516 01	.5998 02
.20	.299-02	.588-03	.9883 04	.545 01	.7823 02
.18	.222-02	.393-03	.9978 04	.578 01	.1044 03
.16	.160-02	.252-03	.1007 05	.617 01	.1432 03
.14	.112-02	.154-03	.1016 05	.663 01	.2035 03
.12	.743-03	.878-04	.1025 05	.721 01	.3031 03
.10	.463-03	.456-04	.1033 05	.794 01	.4821 03
.09	.354-03	.313-04	.1037 05	.839 01	.6242 03
.08	.262-03	.206-04	.1042 05	.893 01	.8469 03
.07	.186-03	.128-04	.1046 05	.958 01	.1185 04
.06	.126-03	.743-05	.1050 05	.104 02	.1746 04
.05	.792-04	.390-05	.1054 05	.114 02	.2764 04
.04	.450-04	.177-05	.1058 05	.128 02	.4853 04
.03	.217-04	.638-06	.1062 05	.149 02	.1004 05
.02	.773-05	.152-06	.1066 05	.183 02	.2800 05
.01	.133-05	.143-07	.1070 05	.253 02	.1622 06

Table 18b. EXPANSION AFTER FREEZING - HYPERBOLIC NOZZLE

$T_o' = 4000°K$, $p_o' = 300$ atm.

$\ell = 0.1$

T	ρ	P	u' (ft/sec.)	M	A
.668	.168 00	.112 00	.6737 04	.209 01	.2032 01
.66	.162 00	.106 00	.6801 04	.210 01	.2097 01
.64	.146 00	.923-01	.6959 04	.218 01	.2277 01
.62	.131 00	.803-01	.7113 04	.226 01	.2483 01
.60	.117 00	.695-01	.7263 04	.235 01	.2719 01
.58	.104 00	.598-01	.7410 04	.244 01	.2991 01
.56	.924-01	.513-01	.7554 04	.253 01	.3305 01
.54	.817-01	.437-01	.7695 04	.262 01	.3669 01
.52	.719-01	.371-01	.7833 04	.272 01	.4093 01
.50	.631-01	.313-01	.7968 04	.282 01	.4590 01
.48	.550-01	.262-01	.8101 04	.292 01	.5175 01
.46	.477-01	.218-01	.8231 04	.303 01	.5869 01
.44	.412-01	.180-01	.8358 04	.315 01	.6697 01
.42	.353-01	.147-01	.8483 04	.327 01	.7692 01
.40	.301-01	.119-01	.8606 04	.339 01	.8897 01
.38	.255-01	.960-02	.8727 04	.353 01	.1037 02
.36	.214-01	.764-02	.8845 04	.367 01	.1218 02
.34	.178-01	.601-02	.8960 04	.382 01	.1444 02
.32	.147-01	.467-02	.9074 04	.399 01	.1728 02
.30	.120-01	.357-02	.9185 04	.416 01	.2090 02
.28	.970-02	.269-02	.9294 04	.435 01	.2558 02
.26	.774-02	.199-02	.9400 04	.456 01	.3171 02
.24	.608-02	.145-02	.9504 04	.479 01	.3989 02
.22	.471-02	.103-02	.9605 04	.504 01	.5102 02
.20	.357-02	.708-03	.9704 04	.533 01	.6652 02
.18	.265-02	.473-03	.9800 04	.566 01	.8872 02
.16	.192-02	.304-03	.9894 04	.604 01	.1217 03
.14	.134-02	.185-03	.9985 04	.650 01	.1728 03
.12	.890-03	.106-03	.1007 05	.706 01	.2573 03
.10	.555-03	.550-04	.1016 05	.778 01	.4091 03
.09	.423-03	.378-04	.1020 05	.822 01	.5338 03
.08	.313-03	.249-04	.1025 05	.875 01	.7183 03
.07	.223-03	.155-04	.1029 05	.939 01	.1005 04
.06	.151-03	.897-05	.1033 05	.102 02	.1481 04
.05	.949-04	.470-05	.1037 05	.112 02	.2343 04
.04	.539-04	.213-05	.1041 05	.126 02	.4112 04
.03	.259-04	.771-06	.1046 05	.146 02	.8503 04
.02	.927-05	.182-06	.1050 05	.180 02	.2371 05
.01	.159-05	.144-07	.1054 05	.262 02	.1373 06

$\ell = 1.0$

T	ρ	P	u' (ft/sec.)	M	A
.57	.895-01	.506-01	.7563 04	.253 01	.3407 01
.56	.843-01	.468-01	.7633 04	.256 01	.3585 01
.54	.745-01	.399-01	.7773 04	.265 01	.3981 01
.52	.656-01	.338-01	.7909 04	.275 01	.4443 01
.50	.575-01	.285-01	.8043 04	.285 01	.4984 01
.48	.502-01	.239-01	.8175 04	.295 01	.5622 01
.46	.435-01	.199-01	.8304 04	.306 01	.6378 01
.44	.376-01	.164-01	.8430 04	.318 01	.7280 01
.42	.322-01	.134-01	.8554 04	.330 01	.8365 01
.40	.275-01	.109-01	.8676 04	.342 01	.9675 01
.38	.232-01	.875-02	.8795 04	.356 01	.1128 02
.36	.195-01	.696-02	.8913 04	.370 01	.1326 02
.34	.163-01	.548-02	.9027 04	.385 01	.1572 02
.32	.134-01	.425-02	.9140 04	.402 01	.1882 02
.30	.110-01	.326-02	.9250 04	.419 01	.2277 02
.28	.884-02	.245-02	.9358 04	.438 01	.2787 02
.26	.705-02	.182-02	.9464 04	.459 01	.3456 02
.24	.554-02	.132-02	.9567 04	.482 01	.4348 02
.22	.429-02	.935-03	.9668 04	.508 01	.5562 02
.20	.326-02	.645-03	.9766 04	.537 01	.7253 02
.18	.242-02	.431-03	.9862 04	.570 01	.9677 02
.16	.175-02	.277-03	.9955 04	.608 01	.1327 03
.14	.122-02	.169-03	.1005 05	.654 01	.1886 03
.12	.810-03	.964-04	.1013 05	.710 01	.2806 03
.10	.505-03	.501-04	.1022 05	.783 01	.4467 03
.09	.386-03	.344-04	.1026 05	.827 01	.5829 03
.08	.285-03	.226-04	.1031 05	.881 01	.7844 03
.07	.203-03	.141-04	.1035 05	.945 01	.1098 04
.06	.137-03	.816-05	.1039 05	.102 02	.1617 04
.05	.864-04	.428-05	.1043 05	.113 02	.2560 04
.04	.490-04	.194-05	.1047 05	.126 02	.4494 04
.03	.236-04	.701-06	.1051 05	.147 02	.9295 04
.02	.843-05	.168-06	.1055 05	.180 02	.2593 05
.01	.145-05	.144-07	.1060 05	.255 02	.1502 06

$\ell = 10$

T	ρ	P	u' (ft/sec.)	M	A
.495	.533-01	.261-01	.811[illegible] 04	.290 01	.534[illegible] 01
.48	.481-01	.229-01	.8210 04	.296 01	[illegible] 01
.46	.417-01	.190-01	.8338 04	.307 01	.6629 01
.44	.360-01	.157-01	[illegible] 04	.319 01	.7567 01
.42	.309-01	.129-01	.8585 04	.331 01	[illegible] 01
.40	.263-01	.104-01	.8709 04	.344 01	[illegible] 02
.38	.223-01	.838-02	.8828 04	.357 01	.1174 02
.36	.187-01	.667-02	.8944 04	.371 01	.1379 02
.34	.156-01	.525-02	.9059 04	.387 01	.1635 02
.32	.128-01	.407-02	.9171 04	.404 01	.1958 02
.30	.105-01	.312-02	.9281 04	.421 01	[illegible] 02
.28	.847-02	.235-02	.9389 04	.440 01	.2900 02
.26	.676-02	.174-02	.9494 04	.461 01	[illegible] 02
.24	.531-02	.126-02	.9597 04	.484 01	.4525 02
.22	.411-02	.895-03	.9697 04	.509 01	.5789 02
.20	.312-02	.618-03	.9795 04	.538 01	.7550 02
.18	.231-02	.413-03	.9891 04	.571 01	.1007 03
.16	.167-02	.265-03	[illegible] 04	.610 01	.1382 03
.14	.117-02	.162-03	.1007 05	.656 01	.1964 03
.12	.776-03	.923-04	.1016 05	.712 01	[illegible] 03
.10	.484-03	.479-04	.1025 05	.785 01	.4653 03
.09	.369-03	.329-04	.1029 05	.830 01	.6072 03
.08	.273-03	.216-04	.1033 05	.883 01	.8173 03
.07	.194-03	.135-04	.1038 05	.947 01	.1144 04
.06	.131-03	.781-05	.1042 05	.103 02	.1685 04
.05	.827-04	.410-05	.1046 05	.113 02	.2668 04
.04	.469-04	.166-05	.1050 05	.127 02	.4684 04
.03	.226-04	.672-06	.1054 05	.147 02	[illegible] 04
.02	.806-05	.159-06	.1058 05	.181 02	.2703 05
.01	.139-05	.144-07	.1062 05	.253 02	.1567 06

Table 19a. EXPANSION AFTER FREEZING - WEDGE NOZZLE

$T_o' = 4000°K$, $p_o' = 1000$ atm.

ℓ = 0.1

T	ρ	P	u' (ft/sec.)	M	A
.697	.200 00	.138 00	.6463 04	.196 01	.1789 01
.68	.183 00	.124 00	.6604 04	.201 01	.1905 01
.66	.165 00	.108 00	.6767 04	.209 01	.2060 01
.64	.149 00	.945-01	.6925 04	.217 01	.2236 01
.62	.134 00	.822-01	.7080 04	.225 01	.2438 01
.60	.120 00	.711-01	.7231 04	.234 01	.2669 01
.58	.107 00	.613-01	.7378 04	.243 01	.2935 01
.56	.946-01	.525-01	.7523 04	.252 01	.3242 01
.54	.836-01	.448-01	.7664 04	.261 01	.3598 01
.52	.736-01	.380-01	.7803 04	.271 01	.4013 01
.50	.646-01	.320-01	.7939 04	.281 01	.4500 01
.48	.563-01	.268-01	.8072 04	.291 01	.5073 01
.46	.489-01	.223-01	.8202 04	.302 01	.5752 01
.44	.422-01	.184-01	.8330 04	.314 01	.6562 01
.42	.362-01	.151-01	.8456 04	.326 01	.7536 01
.40	.308-01	.122-01	.8579 04	.338 01	.8715 01
.38	.261-01	.984-02	.8700 04	.352 01	.1016 02
.36	.219-01	.783-02	.8818 04	.366 01	.1193 02
.34	.183-01	.616-02	.8934 04	.381 01	.1414 02
.32	.151-01	.478-02	.9048 04	.397 01	.1692 02
.30	.123-01	.366-02	.9160 04	.415 01	.2046 02
.28	.994-02	.276-02	.9269 04	.434 01	.2504 02
.26	.793-02	.204-02	.9375 04	.455 01	.3103 02
.24	.623-02	.148-02	.9479 04	.478 01	.3903 02
.22	.482-02	.105-02	.9581 04	.503 01	.4991 02
.20	.366-02	.726-03	.9680 04	.532 01	.6506 02
.18	.272-02	.485-03	.9777 04	.564 01	.8677 02
.16	.196-02	.312-03	.9871 04	.602 01	.1190 03
.14	.137-02	.190-03	.9962 04	.648 01	.1690 03
.12	.912-03	.109-03	.1005 05	.704 01	.2515 03
.10	.569-03	.564-04	.1014 05	.776 01	.3998 03
.09	.434-03	.388-04	.1018 05	.820 01	.5216 03
.08	.321-03	.255-04	.1022 05	.873 01	.7018 03
.07	.229-03	.159-04	.1027 05	.937 01	.9816 03
.06	.155-03	.921-05	.1031 05	.102 02	.1446 04
.05	.974-04	.483-05	.1035 05	.112 02	.2288 04
.04	.553-04	.219-05	.1039 05	.125 02	.4015 04
.03	.266-04	.794-06	.1043 05	.145 02	.8299 04
.02	.952-05	.188-06	.1048 05	.179 02	.2314 05
.01	.164-05	.173-07	.1052 05	.250 02	.1339 06

ℓ = 1.0

T	ρ	P	u' (ft/sec.)	M	A
.609	.116 00	.700-01	.7251 04	.235 01	.2742 01
.60	.110 00	.656-01	.7318 04	.237 01	.2858 01
.58	.983-01	.565-01	.7464 04	.246 01	.3145 01
.56	.872-01	.484-01	.7606 04	.255 01	.3476 01
.54	.771-01	.413-01	.7746 04	.264 01	.3860 01
.52	.679-01	.350-01	.7884 04	.274 01	.4307 01
.50	.595-01	.295-01	.8018 04	.284 01	.4831 01
.48	.519-01	.247-01	.8150 04	.294 01	.5449 01
.46	.451-01	.205-01	.8279 04	.305 01	.6181 01
.44	.389-01	.170-01	.8406 04	.317 01	.7054 01
.42	.334-01	.139-01	.8530 04	.329 01	.8104 01
.40	.284-01	.113-01	.8652 04	.341 01	.9375 01
.38	.241-01	.906-02	.8772 04	.355 01	.1093 02
.36	.202-01	.721-02	.8890 04	.369 01	.1284 02
.34	.168-01	.567-02	.9005 04	.384 01	.1523 02
.32	.139-01	.440-02	.9118 04	.401 01	.1623 02
.30	.113-01	.337-02	.9228 04	.418 01	.2205 02
.28	.915-02	.254-02	.9336 04	.437 01	.2698 02
.26	.730-02	.188-02	.9442 04	.458 01	.3346 02
.24	.574-02	.137-02	.9546 04	.481 01	.4209 02
.22	.444-02	.968-03	.9647 04	.507 01	.5384 02
.20	.337-02	.668-03	.9745 04	.535 01	.7021 02
.18	.250-02	.446-03	.9841 04	.568 01	.9366 02
.16	.181-02	.287-03	.9934 04	.607 01	.1285 03
.14	.126-02	.175-03	.1003 05	.652 01	.1825 03
.12	.839-03	.998-04	.1011 05	.709 01	.2718 03
.10	.523-03	.518-04	.1020 05	.781 01	.4322 03
.09	.399-03	.356-04	.1024 05	.826 01	.5640 03
.08	.295-03	.234-04	.1029 05	.879 01	.7590 03
.07	.210-03	.146-04	.1033 05	.943 01	.1062 04
.06	.142-03	.845-05	.1037 05	.102 02	.1565 04
.05	.894-04	.443-05	.1041 05	.112 02	.2477 04
.04	.508-04	.201-05	.1045 05	.126 02	.4347 04
.03	.244-04	.727-06	.1049 05	.146 02	.8990 04
.02	.873-05	.174-06	.1054 05	.180 02	.2508 05
.01	.150-05	.144-07	.1058 05	.258 02	.1453 06

ℓ = 10

T	ρ	P	u' (ft/sec.)	M	A
.536	.714-01	.379-01	.7819 04	.269 01	.4131 01
.52	.645-01	.332-01	.7928 04	.275 01	.4513 01
.50	.565-01	.280-01	.8062 04	.285 01	.5063 01
.48	.493-01	.234-01	.8193 04	.296 01	.5711 01
.46	.428-01	.195-01	.8321 04	.307 01	.6480 01
.44	.369-01	.161-01	.8448 04	.318 01	.7397 01
.42	.317-01	.132-01	.8571 04	.330 01	.8500 01
.40	.270-01	.107-01	.8693 04	.343 01	.9835 01
.38	.228-01	.859-02	.8812 04	.356 01	.1147 02
.36	.192-01	.684-02	.8929 04	.371 01	.1348 02
.34	.160-01	.538-02	.9044 04	.386 01	.1598 02
.32	.132-01	.417-02	.9156 04	.402 01	.1913 02
.30	.108-01	.320-02	.9266 04	.420 01	.2315 02
.28	.868-02	.241-02	.9374 04	.439 01	.2834 02
.26	.692-02	.178-02	.9479 04	.460 01	.3514 02
.24	.544-02	.129-02	.9582 04	.483 01	.4422 02
.22	.421-02	.918-03	.9683 04	.509 01	.5657 02
.20	.320-02	.633-03	.9781 04	.538 01	.7378 02
.18	.237-02	.423-03	.9876 04	.570 01	.9843 02
.16	.171-02	.272-03	.9969 04	.609 01	.1350 03
.14	.119-02	.166-03	.1006 05	.655 01	.1919 03
.12	.795-03	.945-04	.1015 05	.711 01	.2858 03
.10	.496-03	.491-04	.1023 05	.784 01	.4546 03
.09	.378-03	.337-04	.1028 05	.829 01	.5933 03
.08	.280-03	.222-04	.1032 05	.882 01	.7985 03
.07	.199-03	.138-04	.1036 05	.946 01	.1117 04
.06	.135-03	.800-05	.1040 05	.103 02	.1647 04
.05	.847-04	.420-05	.1044 05	.113 02	.2607 04
.04	.481-04	.190-05	.1049 05	.127 02	.4577 04
.03	.231-04	.666-06	.1053 05	.147 02	.9468 04
.02	.826-05	.165-06	.1057 05	.180 02	.2642 05
.01	.142-05	.144-07	.1061 05	.254 02	.1531 06

Table 19b. EXPANSION AFTER FREEZING - HYPERBOLIC NOZZLE

$T_o' = 4000°K$, $p_o' = 1000$ atm.

54

ℓ = 0.1

T	ρ	P	u' (ft/sec.)	M	A
.766	.215 00	.158 00	.7360 04	.190 01	.1690 01
.76	.209 00	.152 00	.7416 04	.193 01	.1722 01
.74	.192 00	.136 00	.7600 04	.201 01	.1835 01
.72	.175 00	.121 00	.7779 04	.208 01	.1962 01
.70	.160 00	.107 00	.7954 04	.216 01	.2106 01
.68	.145 00	.945-01	.8125 04	.224 01	.2268 01
.66	.132 00	.831-01	.8293 04	.232 01	.2452 01
.64	.119 00	.729-01	.8457 04	.240 01	.2660 01
.62	.107 00	.636-01	.8617 04	.249 01	.2897 01
.60	.962-01	.553-01	.8775 04	.257 01	.3168 01
.58	.861-01	.478-01	.8930 04	.266 01	.3478 01
.56	.768-01	.412-01	.9081 04	.276 01	.3835 01
.54	.682-01	.353-01	.9231 04	.285 01	.4249 01
.52	.603-01	.300-01	.9377 04	.295 01	.4729 01
.50	.531-01	.254-01	.9521 04	.306 01	.5289 01
.48	.465-01	.214-01	.9663 04	.316 01	.5948 01
.46	.406-01	.179-01	.9802 04	.328 01	.6727 01
.44	.352-01	.148-01	.9939 04	.340 01	.7654 01
.42	.303-01	.122-01	.1007 05	.352 01	.8767 01
.40	.259-01	.993-02	.1021 05	.366 01	.1011 02
.38	.220-01	.801-02	.1034 05	.380 01	.1175 02
.36	.186-01	.640-02	.1046 05	.395 01	.1377 02
.34	.155-01	.505-02	.1059 05	.411 01	.1628 02
.32	.128-01	.394-02	.1071 05	.428 01	.1944 02
.30	.105-01	.302-02	.1084 05	.446 01	.2347 02
.28	.852-02	.228-02	.1096 05	.467 01	.2867 02
.26	.680-02	.169-02	.1107 05	.489 01	.3551 02
.24	.536-02	.123-02	.1119 05	.513 01	.4464 02
.22	.415-02	.873-03	.1130 05	.540 01	.5711 02
.20	.315-02	.603-03	.1141 05	.571 01	.7451 02
.18	.233-02	.402-03	.1152 05	.606 01	.9948 02
.16	.169-02	.258-03	.1162 05	.646 01	.1366 03
.14	.118-02	.158-03	.1172 05	.695 01	.1940 03
.12	.785-03	.902-04	.1182 05	.754 01	.2881 03
.10	.493-03	.472-04	.1192 05	.829 01	.4550 03
.09	.379-03	.326-04	.1196 05	.875 01	.5903 03
.08	.283-03	.217-04	.1201 05	.931 01	.7879 03
.07	.203-03	.136-04	.1206 05	.998 01	.1091 04
.06	.139-03	.800-05	.1210 05	.108 02	.1588 04
.05	.891-04	.426-05	.1215 05	.119 02	.2472 04
.04	.516-04	.197-05	.1219 05	.133 02	.4254 04
.03	.255-04	.732-06	.1224 05	.155 02	.8571 04
.02	.945-05	.182-06	.1228 05	.190 02	.2304 05
.01	.173-05	.160-07	.1233 05	.272 02	.1253 06

ℓ = 1.0

T	ρ	P	u' (ft/sec.)	M	A
.648	.760-01	.460-01	.9041 04	.259 01	.3893 01
.64	.731-01	.437-01	.9098 04	.262 01	.4024 01
.62	.656-01	.380-01	.9247 04	.271 01	.4407 01
.60	.588-01	.330-01	.9393 04	.280 01	.4845 01
.58	.524-01	.284-01	.9537 04	.289 01	.5348 01
.56	.466-01	.244-01	.9679 04	.298 01	.5929 01
.54	.413-01	.208-01	.9819 04	.308 01	.6602 01
.52	.364-01	.177-01	.9956 04	.318 01	.7387 01
.50	.319-01	.149-01	.1009 05	.329 01	.8307 01
.48	.279-01	.125-01	.1022 05	.340 01	.9392 01
.46	.242-01	.104-01	.1036 05	.352 01	.1068 02
.44	.209-01	.858-02	.1049 05	.364 01	.1222 02
.42	.179-01	.703-02	.1061 05	.377 01	.1407 02
.40	.153-01	.571-02	.1074 05	.391 01	.1632 02
.38	.129-01	.458-02	.1086 05	.405 01	.1908 02
.36	.108-01	.364-02	.1098 05	.421 01	.2248 02
.34	.901-02	.286-02	.1110 05	.437 01	.2675 02
.32	.742-02	.222-02	.1122 05	.455 01	.3214 02
.30	.604-02	.169-02	.1134 05	.474 01	.3905 02
.28	.486-02	.127-02	.1145 05	.495 01	.4803 02
.26	.386-02	.938-03	.1156 05	.518 01	.5990 02
.24	.302-02	.677-03	.1167 05	.544 01	.7586 02
.22	.232-02	.477-03	.1178 05	.572 01	.9778 02
.20	.175-02	.327-03	.1188 05	.604 01	.1286 03
.18	.129-02	.217-03	.1199 05	.640 01	.1732 03
.16	.923-03	.138-03	.1209 05	.683 01	.2398 03
.14	.638-03	.835-04	.1218 05	.733 01	.3440 03
.12	.422-03	.473-04	.1228 05	.795 01	.5161 03
.10	.262-03	.245-04	.1237 05	.874 01	.8243 03
.09	.200-03	.168-04	.1241 05	.922 01	.1076 04
.08	.149-03	.111-04	.1246 05	.980 01	.1445 04
.07	.106-03	.694-05	.1250 05	.105 02	.2016 04
.06	.721-04	.404-05	.1255 05	.114 02	.2957 04
.05	.457-04	.214-05	.1259 05	.125 02	.4647 04
.04	.262-04	.978-06	.1263 05	.140 02	.8086 04
.03	.128-04	.358-06	.1268 05	.163 02	.1652 05
.02	.464-05	.855-07	.1272 05	.200 02	.4532 05
.01	.822-06	.900-08	.1276 05	.281 02	.2550 06

ℓ = 10

T	ρ	P	u' (ft/sec.)	M	A
.553	.310-01	.158-01	.1008 05	.313 01	.8559 01
.54	.287-01	.143-01	.1017 05	.322 01	.9176 01
.52	.252-01	.121-01	.1030 05	.332 01	.1030 02
.50	.221-01	.102-01	.1043 05	.343 01	.1161 02
.48	.192-01	.851-02	.1056 05	.354 01	.1317 02
.46	.167-01	.706-02	.1068 05	.366 01	.1502 02
.44	.144-01	.582-02	.1081 05	.379 01	.1724 02
.42	.123-01	.475-02	.1093 05	.392 01	.1991 02
.40	.104-01	.385-02	.1105 05	.406 01	.2317 02
.38	.881-02	.308-02	.1117 05	.420 01	.2717 02
.36	.737-02	.245-02	.1129 05	.436 01	.3214 02
.34	.611-02	.191-02	.1141 05	.453 01	.3836 02
.32	.502-02	.148-02	.1152 05	.471 01	.4626 02
.30	.407-02	.113-02	.1164 05	.491 01	.5642 02
.28	.327-02	.843-03	.1175 05	.513 01	.6967 02
.26	.259-02	.620-03	.1185 05	.536 01	.8723 02
.24	.202-02	.446-03	.1196 05	.562 01	.1109 03
.22	.154-02	.313-03	.1207 05	.591 01	.1436 03
.20	.116-02	.213-03	.1217 05	.624 01	.1898 03
.18	.849-03	.141-03	.1227 05	.661 01	.2568 03
.16	.605-03	.892-04	.1236 05	.705 01	.3575 03
.14	.416-03	.537-04	.1246 05	.756 01	.5155 03
.12	.274-03	.303-04	.1255 05	.820 01	.7781 03
.10	.169-03	.156-04	.1264 05	.901 01	.1251 04
.09	.129-03	.107-04	.1268 05	.950 01	.1638 04
.08	.952-04	.702-05	.1273 05	.101 02	.2209 04
.07	.677-04	.437-05	.1277 05	.108 02	.3093 04
.06	.458-04	.253-05	.1281 05	.117 02	.4558 04
.05	.289-04	.133-05	.1286 05	.129 02	.7202 04
.04	.164-04	.607-06	.1290 05	.144 02	.1261 05
.03	.796-05	.219-06	.1294 05	.167 02	.2598 05
.02	.286-05	.534-07	.1298 05	.206 02	.7206 05
.01	.497-06	.530-08	.1302 05	.279 02	.4135 06

Table 20a. EXPANSION AFTER FREEZING - WEDGE NOZZLE

T_o' - 5000°K, p_o' = 100 atm.

$\ell = 0.1$

T	ρ	P	u' (ft/sec.)	M	A
.788	.255 00	.193 00	.7003 04	.178 01	.1498 01
.78	.247 00	.185 00	.7077 04	.182 01	.1530 01
.76	.227 00	.166 00	.7269 04	.189 01	.1622 01
.74	.208 00	.148 00	.7457 04	.197 01	.1726 01
.72	.190 00	.132 00	.7640 04	.204 01	.1843 01
.70	.173 00	.117 00	.7818 04	.212 01	.1975 01
.68	.158 00	.103 00	.7992 04	.220 01	.2125 01
.66	.143 00	.907-01	.8162 04	.228 01	.2294 01
.64	.129 00	.796-01	.8329 04	.236 01	.2486 01
.62	.116 00	.695-01	.8492 04	.244 01	.2704 01
.60	.105 00	.604-01	.8652 04	.253 01	.2954 01
.58	.937-01	.523-01	.8809 04	.262 01	.3240 01
.56	.836-01	.451-01	.8963 04	.271 01	.3568 01
.54	.743-01	.386-01	.9114 04	.281 01	.3948 01
.52	.658-01	.329-01	.9263 04	.291 01	.4390 01
.50	.580-01	.279-01	.9409 04	.301 01	.4905 01
.48	.508-01	.235-01	.9552 04	.312 01	.5510 01
.46	.443-01	.196-01	.9693 04	.323 01	.6225 01
.44	.385-01	.163-01	.9831 04	.335 01	.7075 01
.42	.332-01	.134-01	.9968 04	.347 01	.8094 01
.40	.284-01	.109-01	.1010 05	.361 01	.9324 01
.38	.242-01	.883-02	.1023 05	.375 01	.1082 02
.36	.204-01	.706-02	.1036 05	.390 01	.1267 02
.34	.170-01	.558-02	.1049 05	.405 01	.1496 02
.32	.141-01	.435-02	.1062 05	.423 01	.1784 02
.30	.116-01	.334-02	.1074 05	.441 01	.2151 02
.28	.939-02	.253-02	.1086 05	.461 01	.2625 02
.26	.751-02	.188-02	.1098 05	.483 01	.3246 02
.24	.592-02	.137-02	.1109 05	.507 01	.4075 02
.22	.459-02	.971-03	.1121 05	.534 01	.5205 02
.20	.349-02	.671-03	.1132 05	.564 01	.6780 02
.18	.259-02	.449-03	.1143 05	.599 01	.9038 02
.16	.187-02	.288-03	.1153 05	.639 01	.1238 03
.14	.131-02	.176-03	.1163 05	.687 01	.1756 03
.12	.876-03	.101-03	.1173 05	.746 01	.2603 03
.10	.551-03	.531-04	.1183 05	.820 01	.4101 03
.09	.424-03	.367-04	.1188 05	.866 01	.5313 03
.08	.317-03	.244-04	.1192 05	.921 01	.7083 03
.07	.228-03	.154-04	.1197 05	.988 01	.9795 03
.06	.156-03	.903-05	.1202 05	.107 02	.1423 04
.05	.100-03	.482-05	.1206 05	.118 02	.2212 04
.04	.582-04	.224-05	.1211 05	.132 02	.3797 04
.03	.289-04	.834-06	.1215 05	.153 02	.7628 04
.02	.107-04	.206-06	.1220 05	.188 02	.2042 05
.01	.192-05	.187-07	.1225 05	.269 02	.1103 06

$\ell = 1.0$

T	ρ	P	u' (ft/sec.)	M	A
.692	.115 00	.750-01	.8458 04	.233 01	.2750 01
.68	.108 00	.695-01	.8555 04	.238 01	.2883 01
.66	.981-01	.611-01	.8714 04	.246 01	.3128 01
.64	.885-01	.534-01	.8870 04	.254 01	.3406 01
.62	.796-01	.466-01	.9023 04	.263 01	.3723 01
.60	.714-01	.404-01	.9173 04	.272 01	.4085 01
.58	.638-01	.349-01	.9321 04	.281 01	.4501 01
.56	.567-01	.300-01	.9466 04	.290 01	.4980 01
.54	.503-01	.256-01	.9609 04	.300 01	.5535 01
.52	.444-01	.218-01	.9749 04	.310 01	.6182 01
.50	.390-01	.184-01	.9888 04	.320 01	.6938 01
.48	.341-01	.154-01	.1002 05	.331 01	.7829 01
.46	.296-01	.129-01	.1016 05	.343 01	.8884 01
.44	.256-01	.106-01	.1029 05	.355 01	.1014 02
.42	.220-01	.872-02	.1042 05	.368 01	.1166 02
.40	.188-01	.709-02	.1055 05	.381 01	.1350 02
.38	.159-01	.570-02	.1067 05	.396 01	.1574 02
.36	.134-01	.454-02	.1080 05	.411 01	.1851 02
.34	.111-01	.357-02	.1092 05	.427 01	.2197 02
.32	.920-02	.278-02	.1104 05	.445 01	.2634 02
.30	.751-02	.212-02	.1116 05	.464 01	.3193 02
.28	.606-02	.160-02	.1127 05	.485 01	.3918 02
.26	.482-02	.118-02	.1139 05	.507 01	.4873 02
.24	.378-02	.855-03	.1150 05	.533 01	.6155 02
.22	.291-02	.604-03	.1161 05	.560 01	.7911 02
.20	.220-02	.415-03	.1171 05	.592 01	.1037 03
.18	.163-02	.276-03	.1182 05	.628 01	.1393 03
.16	.117-02	.176-03	.1192 05	.669 01	.1922 03
.14	.810-03	.107-03	.1202 05	.719 01	.2747 03
.12	.538-03	.609-04	.1211 05	.780 01	.4106 03
.10	.336-03	.316-04	.1221 05	.857 01	.6530 03
.09	.257-03	.218-04	.1225 05	.905 01	.8503 03
.08	.191-03	.144-04	.1230 05	.962 01	.1139 04
.07	.137-03	.903-05	.1234 05	.103 02	.1585 04
.06	.932-04	.527-05	.1239 05	.112 02	.2318 04
.05	.593-04	.280-05	.1243 05	.123 02	.3630 04
.04	.341-04	.129-05	.1247 05	.138 02	.6289 04
.03	.167-04	.473-06	.1252 05	.160 02	.1278 05
.02	.612-05	.115-06	.1256 05	.196 02	.3479 05
.01	.110-05	.106-07	.1261 05	.277 02	.1933 06

$\ell = 10$

T	ρ	P	u' (ft/sec.)	M	A
.608	.520-01	.293-01	.9515 04	.282 01	.5407 01
.60	.499-01	.277-01	.9568 04	.288 01	[illegible] 01
.58	.444-01	.239-01	.9710 04	.295 01	.6200 01
.56	.395-01	.205-01	.9849 04	.305 01	.6883 01
.54	.349-01	.175-01	.9986 04	.315 01	[illegible] 01
.52	.307-01	.146-01	.1012 05	.325 01	[illegible] 01
.50	.269-01	.125-01	.1025 05	.336 01	[illegible] 01
.48	.235-01	.105-01	.1038 05	.347 01	.1097 02
.46	.204-01	.869-02	.1051 05	.359 01	.1249 02
.44	.176-01	.717-02	.1064 05	.371 01	.1431 02
.42	.150-01	.586-02	.1077 05	.384 01	.1651 02
.40	.128-01	.475-02	.1089 05	.398 01	.1914 02
.38	.108-01	.381-02	.1101 05	.413 01	.2240 02
.36	.906-02	.303-02	.1113 05	.428 01	.2652 02
.34	.752-02	.237-02	.1125 05	.445 01	[illegible] 02
.32	.619-02	.184-02	.1137 05	.463 01	.3804 02
.30	.503-02	.140-02	.1148 05	.483 01	.4631 02
.28	.404-02	.105-02	.1159 05	.504 01	.5708 02
.26	.320-02	.773-03	.1170 05	.527 01	.7133 02
.24	.250-02	.557-03	.1181 05	.553 01	.9054 02
.22	.192-02	.392-03	.1192 05	.581 01	.1170 03
.20	.144-02	.268-03	.1202 05	.614 01	.1542 03
.18	.106-02	.177-03	.1212 05	.650 01	.2032 03
.16	.757-03	.112-03	.1222 05	.693 01	.2891 03
.14	.522-03	.678-04	.1231 05	.744 01	.4158 03
.12	.345-03	.383-04	.1241 05	.807 01	.6256 03
.10	.213-03	.198-04	.1250 05	.887 01	.1003 04
.09	.163-03	.136-04	.1254 05	.936 01	.1311 04
.08	.120-03	.893-05	.1259 05	.995 01	.1765 04
.07	.858-04	.557-05	.1263 05	.107 02	.2447 04
.06	.582-04	.324-05	.1267 05	.115 02	.3628 04
.05	.368-04	.171-05	.1272 05	.127 02	.5716 04
.04	.210-04	.780-06	.1276 05	.142 02	.9983 04
.03	.102-04	.283-06	.1280 05	.165 02	.2049 05
.02	.368-05	.694-07	.1284 05	.202 02	.5655 05
.01	.646-06	.530-08	.1289 05	.297 02	.3214 06

Table 20b. EXPANSION AFTER FREEZING - HYPERBOLIC NOZZLE
$T_o' = 5000°K$, $p_o' = 100$ atm.

$\ell = 0.1$

T	ρ	P	u' (ft/sec.)	M	A
.714	.150 00	.102 00	.7946 04	.216 01	.2223 01
.70	.140 00	.938-01	.8066 04	.220 01	.2341 01
.68	.127 00	.826-01	.8235 04	.228 01	.2529 01
.66	.115 00	.725-01	.8399 04	.236 01	.2743 01
.64	.104 00	.634-01	.8561 04	.244 01	.2985 01
.62	.932-01	.552-01	.8719 04	.253 01	.3261 01
.60	.835-01	.478-01	.8875 04	.261 01	.3577 01
.58	.745-01	.412-01	.9027 04	.270 01	.3941 01
.56	.662-01	.354-01	.9177 04	.280 01	.4360 01
.54	.586-01	.302-01	.9324 04	.289 01	.4846 01
.52	.517-01	.257-01	.9469 04	.299 01	.5412 01
.50	.454-01	.217-01	.9611 04	.310 01	.6075 01
.48	.396-01	.182-01	.9751 04	.321 01	.6857 01
.46	.344-01	.151-01	.9888 04	.332 01	.7784 01
.44	.297-01	.125-01	.1002 05	.344 01	.8891 01
.42	.255-01	.102-01	.1016 05	.357 01	.1022 02
.40	.217-01	.831-02	.1029 05	.370 01	.1184 02
.38	.184-01	.668-02	.1042 05	.384 01	.1382 02
.36	.154-01	.531-02	.1054 05	.399 01	.1627 02
.34	.129-01	.417-02	.1067 05	.415 01	.1932 02
.32	.106-01	.324-02	.1079 05	.433 01	.2319 02
.30	.863-02	.247-02	.1091 05	.451 01	.2814 02
.28	.695-02	.186-02	.1103 05	.472 01	.3456 02
.26	.552-02	.137-02	.1115 05	.494 01	.4305 02
.24	.432-02	.990-03	.1126 05	.519 01	.5445 02
.22	.332-02	.698-03	.1137 05	.546 01	.7009 02
.20	.251-02	.479-03	.1148 05	.577 01	.9206 02
.18	.185-02	.317-03	.1158 05	.612 01	.1238 03
.16	.132-02	.202-03	.1169 05	.653 01	.1712 03
.14	.916-03	.122-03	.1179 05	.701 01	.2453 03
.12	.607-03	.695-04	.1189 05	.761 01	.3675 03
.10	.377-03	.360-04	.1198 05	.837 01	.5860 03
.09	.288-03	.248-04	.1203 05	.884 01	.7642 03
.08	.214-03	.163-04	.1207 05	.939 01	.1026 04
.07	.153-03	.102-04	.1212 05	.101 02	.1430 04
.06	.104-03	.596-05	.1216 05	.109 02	.2095 04
.05	.660-04	.315-05	.1221 05	.120 02	.3289 04
.04	.378-04	.144-05	.1225 05	.135 02	.5715 04
.03	.185-04	.529-06	.1230 05	.156 02	.1166 05
.02	.673-05	.128-06	.1234 05	.192 02	.3192 05
.01	.120-05	.108-07	.1239 05	.277 02	.1790 06

$\ell = 1.0$

T	ρ	P	u' (ft/sec.)	M	A
.60	.576-01	.325-01	.9301 04	.277 01	.4946 01
.58	.513-01	.280-01	.9446 04	.286 01	.5467 01
.56	.455-01	.240-01	.9589 04	.295 01	.6069 01
.54	.402-01	.204-01	.9730 04	.305 01	.6768 01
.52	.354-01	.173-01	.9868 04	.315 01	.7584 01
.50	.310-01	.146-01	.1000 05	.325 01	.8543 01
.48	.270-01	.122-01	.1014 05	.337 01	.9675 01
.46	.234-01	.101-01	.1027 05	.348 01	.1102 02
.44	.202-01	.835-02	.1040 05	.360 01	.1263 02
.42	.173-01	.682-02	.1053 05	.373 01	.1458 02
.40	.147-01	.552-02	.1066 05	.387 01	.1694 02
.38	.124-01	.443-02	.1078 05	.401 01	.1985 02
.36	.104-01	.351-02	.1090 05	.417 01	.2345 02
.34	.860-02	.275-02	.1102 05	.433 01	.2796 02
.32	.706-02	.213-02	.1114 05	.451 01	.3369 02
.30	.573-02	.162-02	.1126 05	.470 01	.4104 02
.28	.460-02	.121-02	.1137 05	.491 01	.5063 02
.26	.364-02	.891-03	.1148 05	.514 01	.6333 02
.24	.284-02	.641-03	.1159 05	.539 01	.8046 02
.22	.218-02	.450-03	.1170 05	.567 01	.1041 03
.20	.163-02	.307-03	.1181 05	.599 01	.1374 03
.18	.120-02	.203-03	.1191 05	.635 01	.1857 03
.16	.854-03	.129-03	.1201 05	.677 01	.2583 03
.14	.588-03	.775-04	.1211 05	.727 01	.3721 03
.12	.387-03	.437-04	.1220 05	.788 01	.5610 03
.10	.239-03	.225-04	.1229 05	.867 01	.9007 03
.09	.182-03	.154-04	.1234 05	.915 01	.1179 04
.08	.135-03	.101-04	.1238 05	.972 01	.1589 04
.07	.959-04	.631-05	.1243 05	.104 02	.2224 04
.06	.649-04	.366-05	.1247 05	.113 02	.3274 04
.05	.410-04	.193-05	.1251 05	.124 02	.5169 04
.04	.233-04	.877-06	.1256 05	.139 02	.9043 04
.03	.113-04	.319-06	.1260 05	.161 02	.1861 05
.02	.407-05	.762-07	.1264 05	.198 02	.5155 05
.01	.708-06	.540-08	.1269 05	.301 02	.2950 06

$\ell = 10$

T	ρ	P	u' (ft/sec.)	M	A
.513	.270-01	.129-01	.1011 05	.324 01	.9703 01
.50	.248-01	.116-01	.1020 05	.333 01	.1047 02
.48	.216-01	.959-02	.1033 05	.344 01	.1168 02
.46	.187-01	.804-02	.1046 05	.356 01	.1355 02
.44	.161-01	.662-02	.1058 05	.368 01	.1555 02
.42	.138-01	.540-02	.1071 05	.381 01	.1768 02
.40	.117-01	.437-02	.1083 05	.395 01	.2043 02
.38	.985-02	.350-02	.1096 05	.410 01	.2456 02
.36	.823-02	.277-02	.1108 05	.425 01	.2906 02
.34	.682-02	.217-02	.1120 05	.442 01	.3472 02
.32	.559-02	.167-02	.1131 05	.460 01	.4186 02
.30	.453-02	.127-02	.1143 05	.479 01	.5114 02
.28	.363-02	.951-03	.1154 05	.500 01	.6321 02
.26	.287-02	.698-03	.1165 05	.523 01	.7923 02
.24	.223-02	.501-03	.1176 05	.549 01	.1069 03
.22	.171-02	.351-03	.1186 05	.577 01	.1307 03
.20	.128-02	.239-03	.1197 05	.610 01	.1760 03
.18	.937-03	.158-03	.1207 05	.646 01	.2344 03
.16	.666-03	.996-04	.1217 05	.689 01	.3268 03
.14	.458-03	.599-04	.1226 05	.740 01	.4721 03
.12	.300-03	.337-04	.1236 05	.802 01	.7140 03
.10	.185-03	.173-04	.1245 05	.881 01	.1150 04
.09	.141-03	.118-04	.1249 05	.930 01	.1508 04
.08	.104-03	.776-05	.1253 05	.989 01	.2036 04
.07	.738-04	.483-05	.1258 05	.106 02	.2855 04
.06	.498-04	.279-05	.1262 05	.115 02	.4214 04
.05	.314-04	.147-05	.1266 05	.126 02	.6671 04
.04	.178-04	.665-06	.1271 05	.141 02	.1171 05
.03	.859-05	.240-06	.1275 05	.164 02	.2419 05
.02	.307-05	.572-07	.1279 05	.202 02	.6738 05
.01	.530-06	.540-08	.1283 05	.279 02	.3847 06

Table 21a. EXPANSION AFTER FREEZING - WEDGE NOZZLE

$T_o' = 5000°K$, $p_o' = 200$ atm.

ℓ = 0.1

T	ρ	P	u' (ft/sec.)	M	A
.745	.195 00	.140 00	.7495 04	.198 01	.1804 01
.74	.191 00	.136 00	.7550 04	.200 01	.1840 01
.72	.174 00	.120 00	.7730 04	.207 01	.1970 01
.70	.158 00	.106 00	.7906 04	.215 01	.2118 01
.68	.144 00	.937-01	.8077 04	.223 01	.2285 01
.66	.130 00	.823-01	.8245 04	.231 01	.2474 01
.64	.117 00	.720-01	.8410 04	.239 01	.2689 01
.62	.105 00	.627-01	.8571 04	.248 01	.2934 01
.60	.944-01	.544-01	.8729 04	.256 01	.3214 01
.58	.843-01	.470-01	.8885 04	.265 01	.3536 01
.56	.750-01	.404-01	.9037 04	.274 01	.3907 01
.54	.665-01	.345-01	.9186 04	.284 01	.4337 01
.52	.587-01	.293-01	.9333 04	.294 01	.4837 01
.50	.515-01	.247-01	.9478 04	.304 01	.5423 01
.48	.451-01	.208-01	.9619 04	.315 01	.6114 01
.46	.392-01	.173-01	.9759 04	.327 01	.6932 01
.44	.339-01	.143-01	.9896 04	.339 01	.7908 01
.42	.291-01	.117-01	.1003 05	.351 01	.9081 01
.40	.248-01	.953-02	.1016 05	.364 01	.1050 02
.38	.210-01	.767-02	.1029 05	.378 01	.1224 02
.36	.177-01	.611-02	.1042 05	.393 01	.1439 02
.34	.147-01	.480-02	.1055 05	.409 01	.1707 02
.32	.121-01	.373-02	.1067 05	.426 01	.2046 02
.30	.990-02	.285-02	.1079 05	.445 01	.2478 02
.28	.799-02	.215-02	.1091 05	.465 01	.3040 02
.26	.635-02	.159-02	.1103 05	.487 01	.3780 02
.24	.498-02	.115-02	.1115 05	.512 01	.4773 02
.22	.384-02	.810-03	.1126 05	.539 01	.6133 02
.20	.290-02	.557-03	.1137 05	.569 01	.8041 02
.18	.214-02	.370-03	.1148 05	.604 01	.1079 03
.16	.154-02	.236-03	.1158 05	.645 01	.1490 03
.14	.107-02	.143-03	.1168 05	.693 01	.2129 03
.12	.707-03	.814-04	.1178 05	.752 01	.3182 03
.10	.441-03	.423-04	.1188 05	.827 01	.5061 03
.09	.337-03	.291-04	.1192 05	.873 01	.6591 03
.08	.251-03	.192-04	.1197 05	.928 01	.8834 03
.07	.179-03	.121-04	.1202 05	.995 01	.1229 04
.06	.122-03	.764-05	.1206 05	.108 02	.1797 04
.05	.777-04	.373-05	.1211 05	.118 02	.2816 04
.04	.447-04	.172-05	.1215 05	.133 02	.4881 04
.03	.219-04	.629-06	.1220 05	.154 02	.9926 04
.02	.801-05	.153-06	.1224 05	.190 02	.2704 05
.01	.143-05	.136-07	.1229 05	.270 02	.1504 06

ℓ = 1.0

T	ρ	P	u' (ft/sec.)	M	A
.652	.905	.559-01	.8723 04	.248 01	.3356 01
.64	.850-01	.515-01	.8817 04	.253 01	.3537 01
.62	.763-01	.448-01	.8971 04	.261 01	.3872 01
.60	.682-01	.388-01	.9122 04	.270 01	.4256 01
.58	.608-01	.334-01	.9270 04	.279 01	.4698 01
.56	.540-01	.287-01	.9416 04	.288 01	.5208 01
.54	.478-01	.244-01	.9559 04	.298 01	.5799 01
.52	.421-01	.207-01	.9700 04	.308 01	.6490 01
.50	.369-01	.175-01	.9839 04	.319 01	.7299 01
.48	.322-01	.146-01	.9975 04	.330 01	.8254 01
.46	.279-01	.122-01	.1011 05	.341 01	.9389 01
.44	.241-01	.100-01	.1024 05	.353 01	.1075 02
.42	.206-01	.821-02	.1037 05	.366 01	.1238 02
.40	.176-01	.665-02	.1050 05	.380 01	.1437 02
.38	.148-01	.534-02	.1063 05	.394 01	.1681 02
.36	.124-01	.424-02	.1075 05	.409 01	.1982 02
.34	.103-01	.332-02	.1087 05	.426 01	.2360 02
.32	.849-02	.257-02	.1099 05	.443 01	.2838 02
.30	.691-02	.196-02	.1111 05	.462 01	.3452 02
.28	.555-02	.147-02	.1123 05	.483 01	.4250 02
.26	.440-02	.108-02	.1134 05	.505 01	.5306 02
.24	.344-02	.781-03	.1145 05	.530 01	.6729 02
.22	.264-02	.550-03	.1156 05	.558 01	.8684 02
.20	.199-02	.376-03	.1167 05	.589 01	.1144 03
.18	.146-02	.249-03	.1177 05	.625 01	.1543 03
.16	.104-02	.158-03	.1187 05	.667 01	.2140 03
.14	.720-03	.954-04	.1197 05	.716 01	.3076 03
.12	.475-03	.540-04	.1207 05	.777 01	.4624 03
.10	.294-03	.279-04	.1216 05	.854 01	.7402 03
.09	.224-03	.191-04	.1221 05	.901 01	.9672 03
.08	.166-03	.126-04	.1225 05	.958 01	.1301 04
.07	.119-03	.786-05	.1230 05	.103 02	.1817 04
.06	.804-04	.457-05	.1234 05	.111 02	.2670 04
.05	.509-04	.241-05	.1238 05	.122 02	.4205 04
.04	.291-04	.110-05	.1243 05	.137 02	.7333 04
.03	.141-04	.401-06	.1247 05	.159 02	.1503 05
.02	.511-05	.980-07	.1252 05	.195 02	.4141 05
.01	.899-06	.810-08	.1256 05	.281 02	.2347 06

ℓ = 10

T	ρ	P	u' (ft/sec.)	M	A
[illegible]	[illegible]	.236-01	[illegible]	[illegible]	[illegible]
.56	.416-01	.219-01	[illegible]	.298 01	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	.240-01	.111-01	[illegible]	.340 01	.1052 02
.46	.213-01	.921-02	[illegible]	.351 01	[illegible]
.44	.184-01	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	.157-01	[illegible]	[illegible]	.377 01	[illegible]
[illegible]	.134-01	[illegible]	.1073 05	.390 01	[illegible]
.38	.113-01	.402-02	[illegible]	[illegible]	[illegible]
.36	.943-02	.318-02	[illegible]	[illegible]	[illegible]
.34	.781-02	.249-02	[illegible]	[illegible]	[illegible]
.32	.641-02	.192-02	.1121 05	.455 01	.3686 02
.30	.521-02	.146-02	.1133 05	.474 01	[illegible]
.28	.417-02	.110-02	.1144 05	.495 01	.5548 02
.26	.330-02	.825-03	.1155 05	.518 01	[illegible]
.24	.257-02	.579-03	.1166 05	.543 01	[illegible]
.22	.197-02	.406-03	.1177 05	.571 01	.1144 03
.20	.146-02	.277-03	.1187 05	.603 01	.1511 03
.18	.106-02	.183-03	.1197 05	.640 01	.2045 03
.16	.771-03	.116-03	.1207 05	.682 01	.2847 03
.14	.530-03	.695-04	.1217 05	.732 01	.4107 03
.12	.348-03	.392-04	.1226 05	.794 01	.6200 03
.10	.215-03	.202-04	.1236 05	.873 01	.9968 03
.09	.164-03	.138-04	.1240 05	.921 01	.1306 04
.08	.121-03	.907-05	.1244 05	.979 01	.1761 04
.07	.860-04	.565-05	.1249 05	.105 02	.2467 04
.06	.581-04	.327-05	.1253 05	.114 02	.3636 04
.05	.367-04	.172-05	.1256 05	.125 02	.5748 04
.04	.209-04	.782-06	.1262 05	.140 02	.1007 05
.03	.101-04	.283-06	.1266 05	.162 02	.2076 05
.02	.362-05	.681-07	.1270 05	.199 02	.5766 05
.01	.627-06	.540-08	.1275 05	.291 02	.3317 06

Table 21b. EXPANSION AFTER FREEZING - HYPERBOLIC NOZZLE

$T_o' = 5000°K$, $p_o' = 200$ atm.

ℓ = 0.1

T	ρ	P	u' (ft/sec.)	M	A
.679	.121 00	.785-01	.8255 04	.230 01	.2639 01
.66	.110 00	.693-01	.8411 04	.236 01	.2853 01
.64	.989-01	.605-01	.8572 04	.245 01	.3109 01
.62	.888-01	.526-01	.8730 04	.253 01	.3401 01
.60	.794-01	.456-01	.8885 04	.262 01	.3735 01
.58	.708-01	.393-01	.9037 04	.271 01	.4119 01
.56	.629-01	.337-01	.9187 04	.280 01	.4563 01
.54	.556-01	.287-01	.9334 04	.290 01	.5078 01
.52	.490-01	.243-01	.9478 04	.300 01	.5679 01
.50	.429-01	.205-01	.9620 04	.310 01	.6384 01
.48	.374-01	.172-01	.9759 04	.321 01	.7215 01
.46	.325-01	.143-01	.9897 04	.333 01	.8203 01
.44	.280-01	.118-01	.1003 05	.345 01	.9385 01
.42	.240-01	.964-02	.1016 05	.357 01	.1081 02
.40	.204-01	.781-02	.1030 05	.371 01	.1254 02
.38	.173-01	.627-02	.1042 05	.385 01	.1466 02
.36	.145-01	.497-02	.1055 05	.400 01	.1729 02
.34	.120-01	.390-02	.1067 05	.416 01	.2057 02
.32	.987-02	.302-02	.1080 05	.433 01	.2474 02
.30	.803-02	.230-02	.1092 05	.452 01	.3008 02
.28	.645-02	.173-02	.1104 05	.472 01	.3703 02
.26	.512-02	.127-02	.1115 05	.495 01	.4622 02
.24	.399-02	.916-03	.1126 05	.519 01	.5860 02
.22	.305-02	.645-03	.1138 05	.547 01	.7562 02
.20	.230-02	.441-03	.1148 05	.577 01	.9960 02
.18	.169-02	.291-03	.1159 05	.613 01	.1343 03
.16	.121-02	.185-03	.1169 05	.653 01	.1864 03
.14	.835-03	.112-03	.1179 05	.702 01	.2678 03
.12	.551-03	.632-04	.1189 05	.762 01	.4027 03
.10	.341-03	.326-04	.1198 05	.838 01	.6446 03
.09	.260-03	.224-04	.1203 05	.884 01	.8424 03
.08	.193-03	.147-04	.1208 05	.940 01	.1133 04
.07	.137-03	.919-05	.1212 05	.101 02	.1583 04
.06	.931-04	.534-05	.1217 05	.109 02	.2327 04
.05	.589-04	.282-05	.1221 05	.120 02	.3665 04
.04	.336-04	.129-05	.1226 05	.135 02	.6394 04
.03	.163-04	.468-06	.1230 05	.156 02	.1311 05
.02	.591-05	.113-06	.1234 05	.192 02	.3615 05
.01	.104-05	.110-07	.1239 05	.264 02	.2053 06

ℓ = 1.0

T	ρ	P	u' (ft/sec.)	M	A
.575	.510-01	.278-01	.9380 04	.284 01	.5511 01
.56	.466-01	.247-01	.9488 04	.291 01	.5964 01
.54	.411-01	.210-01	.9630 04	.301 01	.6653 01
.52	.362-01	.178-01	.9769 04	.311 01	.7458 01
.50	.317-01	.150-01	.9907 04	.322 01	.8404 01
.48	.276-01	.125-01	.1004 05	.333 01	.9521 01
.46	.239-01	.104-01	.1018 05	.344 01	.1085 02
.44	.206-01	.856-02	.1031 05	.356 01	.1244 02
.42	.176-01	.699-02	.1044 05	.369 01	.1437 02
.40	.149-01	.566-02	.1056 05	.383 01	.1671 02
.38	.126-01	.453-02	.1069 05	.397 01	.1958 02
.36	.105-01	.359-02	.1081 05	.412 01	.2315 02
.34	.873-02	.281-02	.1093 05	.429 01	.2763 02
.32	.716-02	.217-02	.1105 05	.446 01	.3331 02
.30	.581-02	.165-02	.1117 05	.465 01	.4061 02
.28	.466-02	.123-02	.1128 05	.486 01	.5014 02
.26	.368-02	.907-03	.1140 05	.509 01	.6277 02
.24	.287-02	.652-03	.1151 05	.534 01	.7984 02
.22	.220-02	.457-03	.1162 05	.562 01	.1034 03
.20	.165-02	.312-03	.1172 05	.593 01	.1366 03
.18	.121-02	.205-03	.1183 05	.629 01	.1849 03
.16	.858-03	.130-03	.1193 05	.671 01	.2575 03
.14	.590-03	.782-04	.1202 05	.720 01	.3715 03
.12	.388-03	.440-04	.1212 05	.781 01	.5610 03
.10	.239-03	.226-04	.1221 05	.859 01	.9023 03
.09	.182-03	.155-04	.1226 05	.906 01	.1182 04
.08	.134-03	.102-04	.1230 05	.964 01	.1595 04
.07	.955-04	.633-05	.1235 05	.103 02	.2235 04
.06	.646-04	.367-05	.1239 05	.112 02	.3295 04
.05	.407-04	.193-05	.1243 05	.123 02	.5210 04
.04	.231-04	.875-06	.1248 05	.138 02	.9132 04
.03	.112-04	.317-06	.1252 05	.160 02	.1884 05
.02	.401-05	.770-07	.1256 05	.196 02	.5237 05
.01	.694-06	.550-08	.1261 05	.294 02	.3014 06

ℓ = 10

T	ρ	P	u' (ft/sec.)	M	A
.49	.255-01	.118-01	.1011 05	.330 01	.1023 02
.48	.238-01	.108-01	.1018 05	.338 01	.1090 02
.46	.206-01	.892-02	.1031 05	.349 01	.1243 02
.44	.177-01	.734-02	.1044 05	.362 01	.1427 02
.42	.151-01	.599-02	.1057 05	.375 01	.1649 02
.40	.126-01	.484-02	.1069 05	.388 01	.1920 02
.38	.108-01	.388-02	.1081 05	.403 01	.2252 02
.36	.904-02	.307-02	.1094 05	.418 01	.2666 02
.34	.749-02	.240-02	.1106 05	.435 01	.3184 02
.32	.614-02	.185-02	.1117 05	.452 01	.3843 02
.30	.498-02	.141-02	.1129 05	.471 01	.4691 02
.28	.399-02	.105-02	.1140 05	.492 01	.5798 02
.26	.315-02	.772-03	.1152 05	.515 01	.7268 02
.24	.245-02	.554-03	.1163 05	.541 01	.9255 02
.22	.187-02	.388-03	.1173 05	.569 01	.1200 03
.20	.140-02	.265-03	.1184 05	.600 01	.1588 03
.18	.103-02	.174-03	.1194 05	.637 01	.2152 03
.16	.730-03	.110-03	.1204 05	.679 01	.3001 03
.14	.501-03	.661-04	.1214 05	.729 01	.4337 03
.12	.329-03	.372-04	.1223 05	.790 01	.6561 03
.10	.202-03	.191-04	.1232 05	.869 01	.1057 04
.09	.154-03	.130-04	.1237 05	.917 01	.1387 04
.08	.113-03	.856-05	.1241 05	.974 01	.1873 04
.07	.806-04	.532-05	.1245 05	.104 02	.2627 04
.06	.544-04	.308-05	.1250 05	.113 02	.3878 04
.05	.342-04	.161-05	.1254 05	.124 02	.6142 04
.04	.194-04	.732-06	.1258 05	.139 02	.1078 05
.03	.936-05	.264-06	.1263 05	.162 02	.2230 05
.02	.335-05	.633-07	.1267 05	.199 02	.6219 05
.01	.576-06	.550-08	.1271 05	.280 02	.3602 05

Table 22a. EXPANSION AFTER FREEZING - WEDGE NOZZLE

$T_o' = 5000°K$, $p_o' = 300$ atm.

ℓ = 0.1

T	ρ	P	u' (ft/sec.)	M	A
.718	.165 00	.114 00	.7765 04	.210 01	.2058 01
.70	.152 00	.102 00	.7918 04	.216 01	.2194 01
.68	.138 00	.896-01	.8089 04	.223 01	.2370 01
.66	.124 00	.788-01	.8257 04	.231 01	.2569 01
.64	.112 00	.689-01	.8421 04	.240 01	.2796 01
.62	.101 00	.599-01	.8582 04	.248 01	.3054 01
.60	.900-01	.519-01	.8740 04	.257 01	.3350 01
.58	.803-01	.448-01	.8895 04	.266 01	.3690 01
.56	.714-01	.384-01	.9047 04	.275 01	.4083 01
.54	.632-01	.328-01	.9196 04	.285 01	.4539 01
.52	.557-01	.278-01	.9342 04	.295 01	.5070 01
.50	.488-01	.235-01	.9486 04	.305 01	.5692 01
.48	.425-01	.196-01	.9628 04	.316 01	.6426 01
.46	.370-01	.163-01	.9767 04	.327 01	.7298 01
.44	.319-01	.135-01	.9904 04	.339 01	.8339 01
.42	.274-01	.110-01	.1004 05	.352 01	.9592 01
.40	.233-01	.896-02	.1017 05	.365 01	.1111 02
.38	.197-01	.720-02	.1030 05	.379 01	.1298 02
.36	.165-01	.572-02	.1043 05	.394 01	.1528 02
.34	.137-01	.449-02	.1056 05	.410 01	.1817 02
.32	.113-01	.348-02	.1068 05	.427 01	.2182 02
.30	.921-02	.266-02	.1080 05	.446 01	.2649 02
.28	.741-02	.199-02	.1092 05	.466 01	.3256 02
.26	.588-02	.147-02	.1104 05	.488 01	.4059 02
.24	.460-02	.106-02	.1115 05	.512 01	.5138 02
.22	.354-02	.747-03	.1126 05	.540 01	.6621 02
.20	.266-02	.512-03	.1137 05	.570 01	.8705 02
.18	.196-02	.339-03	.1148 05	.605 01	.1172 03
.16	.140-02	.216-03	.1158 05	.645 01	.1623 03
.14	.959-03	.130-03	.1169 05	.694 01	.2328 03
.12	.641-03	.739-04	.1178 05	.752 01	.3493 03
.10	.398-03	.382-04	.1188 05	.828 01	.5578 03
.09	.304-03	.263-04	.1193 05	.874 01	.7281 03
.08	.225-03	.173-04	.1197 05	.929 01	.9782 03
.07	.161-03	.108-04	.1202 05	.996 01	.1365 04
.06	.109-03	.629-05	.1206 05	.108 02	.2002 04
.05	.692-04	.232-05	.1211 05	.119 02	.3148 04
.04	.396-04	.152-05	.1215 05	.133 02	.5479 04
.03	.193-04	.556-06	.1220 05	.154 02	.1120 05
.02	.700-05	.135-06	.1224 05	.190 02	.3076 05
.01	.124-05	.110-07	.1229 05	.276 02	.1733 06

ℓ = 1.0

T	ρ	P	u' (ft/sec.)	M	A
.625	.775-01	.460-01	.8872 04	.258 01	.3834 01
.62	.754-01	.444-01	.8911 04	.259 01	.3924 01
.60	.674-01	.384-01	.9063 04	.268 01	.4316 01
.58	.600-01	.331-01	.9212 04	.277 01	.4767 01
.56	.533-01	.284-01	.9358 04	.286 01	.5288 01
.54	.471-01	.242-01	.9502 04	.296 01	.5893 01
.52	.414-01	.205-01	.9644 04	.306 01	.6599 01
.50	.363-01	.172-01	.9783 04	.317 01	.7429 01
.48	.316-01	.144-01	.9921 04	.328 01	.8408 01
.46	.274-01	.120-01	.1006 05	.339 01	.9573 01
.44	.236-01	.987-02	.1019 05	.351 01	.1097 02
.42	.202-01	.806-02	.1032 05	.364 01	.1265 02
.40	.172-01	.653-02	.1045 05	.377 01	.1469 02
.38	.145-01	.523-02	.1057 05	.392 01	.1721 02
.36	.121-01	.415-02	.1070 05	.407 01	.2032 02
.34	.101-01	.325-02	.1082 05	.423 01	.2422 02
.32	.826-02	.251-02	.1094 05	.441 01	.2917 02
.30	.671-02	.191-02	.1106 05	.460 01	.3552 02
.28	.538-02	.143-02	.1118 05	.480 01	.4381 02
.26	.426-02	.105-02	.1129 05	.503 01	.5478 02
.24	.332-02	.758-03	.1140 05	.528 01	.6958 02
.22	.255-02	.532-03	.1151 05	.555 01	.8997 02
.20	.191-02	.363-03	.1162 05	.586 01	.1187 03
.18	.140-02	.240-03	.1172 05	.622 01	.1605 03
.16	.999-03	.152-03	.1183 05	.663 01	.2231 03
.14	.688-03	.915-04	.1192 05	.713 01	.3214 03
.12	.453-03	.516-04	.1202 05	.773 01	.4845 03
.10	.280-03	.266-04	.1211 05	.850 01	.7778 03
.09	.213-03	.182-04	.1216 05	.897 01	.1018 04
.08	.157-03	.120-04	.1220 05	.954 01	.1372 04
.07	.112-03	.746-05	.1225 05	.102 02	.1920 04
.06	.759-04	.432-05	.1229 05	.111 02	.2827 04
.05	.479-04	.227-05	.1234 05	.122 02	.4463 04
.04	.273-04	.104-05	.1238 05	.137 02	.7808 04
.03	.132-04	.377-06	.1243 05	.158 02	.1607 05
.02	.475-05	.908-07	.1247 05	.194 02	.4452 05
.01	.827-06	.820-08	.1251 05	.273 02	.2548 06

ℓ = 10

T	ρ	P	u' (ft/sec.)	M	A
.546	.402-01	.207-01	.9646 04	.300 01	.6799 01
.54	.387-01	.197-01	.9688 04	.303 01	.7030 01
.52	.340-01	.167-01	.9827 04	.313 01	.7884 01
.50	.298-01	.141-01	.9963 04	.324 01	.8898 01
.48	.259-01	.118-01	.1010 05	.335 01	.1007 02
.46	.224-01	.975-02	.1023 05	.346 01	.1149 02
.44	.193-01	.803-02	.1036 05	.359 01	.1318 02
.42	.165-01	.655-02	.1049 05	.371 01	.1522 02
.40	.140-01	.530-02	.1062 05	.385 01	.1771 02
.38	.118-01	.424-02	.1074 05	.399 01	.2077 02
.36	.988-02	.336-02	.1086 05	.415 01	.2456 02
.34	.818-02	.263-02	.1098 05	.431 01	.2932 02
.32	.671-02	.203-02	.1110 05	.449 01	.3537 02
.30	.545-02	.154-02	.1122 05	.468 01	.4315 02
.28	.436-02	.115-02	.1133 05	.489 01	.5330 02
.26	.345-02	.847-03	.1145 05	.512 01	.6677 02
.24	.269-02	.609-03	.1156 05	.537 01	.8498 02
.22	.205-02	.427-03	.1166 05	.565 01	.1101 03
.20	.154-02	.291-03	.1177 05	.596 01	.1456 03
.18	.113-02	.192-03	.1187 05	.632 01	.1972 03
.16	.801-03	.121-03	.1197 05	.674 01	.2748 03
.14	.551-03	.728-04	.1207 05	.724 01	.3967 03
.12	.361-03	.410-04	.1216 05	.785 01	.5996 03
.10	.223-03	.210-04	.1226 05	.863 01	.9654 03
.09	.169-03	.144-04	.1230 05	.911 01	.1265 04
.08	.125-03	.945-05	.1235 05	.968 01	.1708 04
.07	.888-04	.587-05	.1239 05	.104 02	.2395 04
.06	.600-04	.340-05	.1243 05	.112 02	.3533 04
.05	.378-04	.178-05	.1248 05	.123 02	.5592 04
.04	.215-04	.812-06	.1252 05	.139 02	.9810 04
.03	.104-04	.295-06	.1256 05	.160 02	.2026 05
.02	.371-05	.688-07	.1261 05	.198 02	.5641 05
.01	.640-06	.550-08	.1265 05	.290 02	.3257 06

Table 22b. EXPANSION AFTER FREEZING - HYPERBOLIC NOZZLE
$T_o' = 5000°K$, $p_o' = 300$ atm.

ℓ = 0.1

T	ρ	P	u' (ft/sec.)	M	A
.59	.747-01	.426-01	.8815 04	.263 01	.3963 01
.58	.704-01	.395-01	.8892 04	.265 01	.4167 01
.56	.624-01	.338-01	.9044 04	.275 01	.4621 01
.54	.551-01	.268-01	.9193 04	.284 01	.5149 01
.52	.485-01	.244-01	.9339 04	.294 01	.5766 01
.50	.424-01	.205-01	.9483 04	.305 01	.6490 01
.48	.369-01	.171-01	.9624 04	.315 01	.7347 01
.46	.320-01	.142-01	.9763 04	.327 01	.8366 01
.44	.275-01	.117-01	.9900 04	.339 01	.9587 01
.42	.235-01	.955-02	.1003 05	.351 01	.1106 02
.40	.200-01	.773-02	.1017 05	.364 01	.1286 02
.38	.168-01	.619-02	.1030 05	.378 01	.1506 02
.36	.141-01	.490-02	.1042 05	.393 01	.1780 02
.34	.117-01	.383-02	.1055 05	.409 01	.2123 02
.32	.955-02	.296-02	.1067 05	.426 01	.2559 02
.30	.775-02	.225-02	.1079 05	.445 01	.3119 02
.28	.621-02	.168-02	.1091 05	.465 01	.3851 02
.26	.491-02	.123-02	.1103 05	.487 01	.4821 02
.24	.382-02	.387-03	.1114 05	.511 01	.6131 02
.22	.292-02	.621-03	.1126 05	.539 01	.7938 02
.20	.219-02	.423-03	.1137 05	.569 01	.1049 03
.18	.160-02	.279-03	.1147 05	.604 01	.1420 03
.16	.114-02	.176-03	.1158 05	.644 01	.1979 03
.14	.783-03	.106-03	.1168 05	.692 01	.2856 03
.12	.514-03	.596-04	.1177 05	.751 01	.4314 03
.10	.317-03	.306-04	.1187 05	.826 01	.6943 03
.09	.241-03	.210-04	.1192 05	.872 01	.9100 03
.08	.178-03	.137-04	.1196 05	.927 01	.1228 04
.07	.126-03	.855-05	.1201 05	.994 01	.1722 04
.05	.853-04	.495-05	.1205 05	.108 02	.2540 04
.05	.537-04	.260-05	.1210 05	.118 02	.4019 04
.04	.305-04	.118-05	.1214 05	.133 02	.7049 04
.03	.147-04	.426-06	.1219 05	.154 02	.1456 05
.02	.526-05	.101-06	.1223 05	.189 02	.4053 05
.01	.908-06	.840-08	.1228 05	.273 02	.2342 06

ℓ = 1.0

T	ρ	P	u' (ft/sec.)	M	A
.499	.368-01	.177-01	.9609 04	.310 01	.7380 01
.48	.322-01	.149-01	.9742 04	.320 01	.8310 01
.46	.279-01	.124-01	.9879 04	.331 01	.9470 01
.44	.240-01	.102-01	.1001 05	.343 01	.1086 02
.42	.205-01	.831-02	.1015 05	.356 01	.1254 02
.40	.174-01	.672-02	.1028 05	.369 01	.1459 02
.38	.147-01	.538-02	.1041 05	.383 01	.1710 02
.36	.123-01	.425-02	.1053 05	.398 01	.2023 02
.34	.101-01	.333-02	.1066 05	.414 01	.2414 02
.32	.831-02	.257-02	.1078 05	.431 01	.2912 02
.30	.674-02	.195-02	.1090 05	.450 01	.3553 02
.28	.540-02	.146-02	.1102 05	.470 01	.4390 02
.26	.426-02	.107-02	.1113 05	.493 01	.5500 02
.24	.331-02	.767-03	.1125 05	.517 01	.7001 02
.22	.253-02	.538-03	.1136 05	.544 01	.9073 02
.20	.190-02	.366-03	.1146 05	.575 01	.1200 03
.18	.139-02	.241-03	.1157 05	.610 01	.1627 03
.16	.986-03	.152-03	.1167 05	.651 01	.2268 03
.14	.676-03	.913-04	.1177 05	.699 01	.3277 03
.12	.443-03	.513-04	.1187 05	.758 01	.4958 03
.10	.273-03	.263-04	.1196 05	.834 01	.7990 03
.09	.207-03	.180-04	.1201 05	.880 01	.1048 04
.08	.153-03	.118-04	.1206 05	.936 01	.1416 04
.07	.109-03	.733-05	.1210 05	.100 02	.1986 04
.06	.733-04	.424-05	.1215 05	.109 02	.2933 04
.05	.461-04	.222-05	.1219 05	.119 02	.4646 04
.04	.261-04	.101-05	.1223 05	.134 02	.8161 04
.03	.126-04	.364-06	.1228 05	.155 02	.1689 05
.02	.449-05	.874-07	.1232 05	.191 02	.4713 05
.01	.772-06	.840-08	.1237 05	.262 02	.2734 06

ℓ = 10

T	ρ	P	u' (ft/sec.)	M	A
.429	.205-01	.848-02	.1014 05	.350 01	.1256 02
.42	.191-01	.773-02	.1020 05	.357 01	.1341 02
.40	.162-01	.625-02	.1033 05	.371 01	.1560 02
.38	.136-01	.500-02	.1045 05	.385 01	.1830 02
.36	.114-01	.396-02	.1058 05	.400 01	.2164 02
.34	.944-02	.309-02	.1070 05	.416 01	.2584 02
.32	.773-02	.239-02	.1082 05	.433 01	.3117 02
.30	.627-02	.181-02	.1094 05	.452 01	.3804 02
.28	.502-02	.136-02	.1106 05	.472 01	.4700 02
.26	.396-02	.994-03	.1118 05	.495 01	.5890 02
.24	.308-02	.713-03	.1129 05	.519 01	.7499 02
.22	.236-02	.500-03	.1140 05	.546 01	.9720 02
.20	.176-02	.340-03	.1151 05	.577 01	.1286 03
.18	.129-02	.224-03	.1161 05	.612 01	.1743 03
.16	.916-03	.141-03	.1172 05	.653 01	.2431 03
.14	.629-03	.849-04	.1181 05	.702 01	.3513 03
.12	.412-03	.477-04	.1191 05	.761 01	.5315 03
.10	.254-03	.245-04	.1200 05	.837 01	.8567 03
.09	.193-03	.167-04	.1205 05	.883 01	.1124 04
.08	.142-03	.110-04	.1210 05	.939 01	.1516 04
.07	.101-03	.681-05	.1214 05	.101 02	.2130 04
.06	.681-04	.394-05	.1219 05	.109 02	.3146 04
.05	.428-04	.206-05	.1223 05	.120 02	.4984 04
.04	.243-04	.936-06	.1227 05	.134 02	.8756 04
.03	.117-04	.338-06	.1232 05	.156 02	.1812 05
.02	.417-05	.817-07	.1236 05	.191 02	.5058 05
.01	.717-06	.560-08	.1241 05	.290 02	.2934 06

Table 23a. EXPANSION AFTER FREEZING - WEDGE NOZZLE
$T_o' = 5000°K$, $p_o' = 1000$ atm.

ℓ = 0.1

T	ρ	P	u' (ft/sec.)	M	A
.638	.107 00	.665-01	.8335 04	.239 01	.2913 01
.62	.974-01	.586-01	.8481 04	.245 01	.3159 01
.60	.870-01	.506-01	.8640 04	.253 01	.3470 01
.58	.775-01	.436-01	.8796 04	.262 01	.3828 01
.56	.687-01	.373-01	.8950 04	.271 01	.4243 01
.54	.607-01	.318-01	.9100 04	.281 01	.4725 01
.52	.534-01	.269-01	.9248 04	.291 01	.5288 01
.50	.467-01	.226-01	.9393 04	.301 01	.5948 01
.48	.407-01	.189-01	.9536 04	.312 01	.6729 01
.46	.352-01	.157-01	.9676 04	.323 01	.7658 01
.44	.303-01	.129-01	.9814 04	.335 01	.8771 01
.42	.259-01	.106-01	.9950 04	.348 01	.1011 02
.40	.220-01	.854-02	.1008 05	.361 01	.1175 02
.38	.186-01	.684-02	.1021 05	.375 01	.1376 02
.36	.155-01	.542-02	.1034 05	.390 01	.1624 02
.34	.129-01	.424-02	.1047 05	.406 01	.1937 02
.32	.106-01	.328-02	.1059 05	.423 01	.2332 02
.30	.857-02	.249-02	.1072 05	.441 01	.2841 02
.28	.687-02	.186-02	.1084 05	.461 01	.3505 02
.26	.543-02	.137-02	.1095 05	.483 01	.4385 02
.24	.423-02	.984-03	.1107 05	.507 01	.5573 02
.22	.324-02	.690-03	.1118 05	.534 01	.7211 02
.20	.243-02	.471-03	.1129 05	.565 01	.9523 02
.18	.178-02	.310-03	.1140 05	.599 01	.1288 03
.16	.127-02	.196-03	.1150 05	.639 01	.1793 03
.14	.871-03	.118-03	.1160 05	.687 01	.2585 03
.12	.571-03	.665-04	.1170 05	.745 01	.3902 03
.10	.353-03	.342-04	.1180 05	.820 01	.6274 03
.09	.268-03	.234-04	.1185 05	.866 01	.8218 03
.08	.198-03	.154-04	.1189 05	.920 01	.1108 04
.07	.141-03	.955-05	.1194 05	.987 01	.1553 04
.06	.951-04	.553-05	.1198 05	.107 02	.2289 04
.05	.599-04	.291-05	.1203 05	.118 02	.3619 04
.04	.341-04	.132-05	.1207 05	.132 02	.6342 04
.03	.165-04	.479-06	.1212 05	.153 02	.1308 05
.02	.590-05	.116-06	.1216 05	.187 02	.3637 05
.01	.102-05	.112-07	.1221 05	.257 02	.2094 06

ℓ = 1.0

T	ρ	P	u' (ft/sec.)	M	A
.552	.563-01	.300-01	.9164 04	.282 01	.5059 01
.54	.522-01	.272-01	.9252 04	.286 01	.5402 01
.52	.459-01	.230-01	.9397 04	.296 01	.6052 01
.50	.401-01	.194-01	.9540 04	.307 01	.6815 01
.48	.349-01	.162-01	.9681 04	.317 01	.7718 01
.46	.302-01	.134-01	.9819 04	.329 01	.8792 01
.44	.260-01	.111-01	.9955 04	.341 01	.1008 02
.42	.222-01	.902-02	.1009 05	.353 01	.1163 02
.40	.189-01	.729-02	.1022 05	.367 01	.1353 02
.38	.159-01	.584-02	.1035 05	.381 01	.1586 02
.36	.133-01	.462-02	.1048 05	.396 01	.1874 02
.34	.110-01	.361-02	.1060 05	.412 01	.2237 02
.32	.902-02	.279-02	.1072 05	.429 01	.2697 02
.30	.732-02	.212-02	.1084 05	.447 01	.3289 02
.28	.586-02	.158-02	.1096 05	.468 01	.4062 02
.26	.463-02	.116-02	.1108 05	.490 01	.5088 02
.24	.360-02	.835-03	.1119 05	.514 01	.6473 02
.22	.275-02	.585-03	.1130 05	.541 01	.8386 02
.20	.206-02	.398-03	.1141 05	.572 01	.1109 03
.18	.151-02	.262-03	.1152 05	.607 01	.1502 03
.16	.107-02	.166-03	.1162 05	.647 01	.2094 03
.14	.736-03	.996-04	.1172 05	.696 01	.3023 03
.12	.483-03	.560-04	.1182 05	.755 01	.4571 03
.10	.298-03	.287-04	.1191 05	.830 01	.7361 03
.09	.226-03	.197-04	.1196 05	.876 01	.9652 03
.08	.167-03	.129-04	.1201 05	.931 01	.1303 04
.07	.118-03	.801-05	.1205 05	.998 01	.1828 04
.06	.800-04	.464-05	.1210 05	.108 02	.2698 04
.05	.503-04	.243-05	.1214 05	.119 02	.4272 04
.04	.286-04	.110-05	.1219 05	.133 02	.7499 04
.03	.138-04	.398-06	.1223 05	.155 02	.1550 05
.02	.492-05	.958-07	.1227 05	.190 02	.4322 05
.01	.847-06	.840-08	.1232 05	.268 02	.2501 06

ℓ = 10

T	ρ	P	u' (ft/sec.)	M	A
.481	.318-01	.148-01	.9750 04	.319 01	.8417 01
.48	.316-01	.146-01	.9757 04	.320 01	.8471 01
.46	.273-01	.121-01	.9804 04	.332 01	.9064 01
.44	.235-01	.997-02	.1003 05	.344 01	.1107 02
.42	.201-01	.814-02	.1016 05	.356 01	.1270 02
.40	.170-01	.658-02	.1029 05	.369 01	.1487 02
.38	.144-01	.526-02	.1042 05	.384 01	.1744 02
.36	.120-01	.417-02	.1055 05	.399 01	.2052 02
.34	.993-02	.326-02	.1067 05	.415 01	.2462 02
.32	.814-02	.251-02	.1079 05	.432 01	.2979 02
.30	.660-02	.191-02	.1091 05	.451 01	.3624 02
.28	.526-02	.143-02	.1103 05	.471 01	.4477 02
.26	.417-02	.105-02	.1115 05	.493 01	.5610 02
.24	.325-02	.751-03	.1126 05	.518 01	.7142 02
.22	.248-02	.526-03	.1137 05	.545 01	.9256 02
.20	.186-02	.358-03	.1148 05	.576 01	.1225 03
.18	.136-02	.236-03	.1158 05	.611 01	.1654 03
.16	.965-03	.149-03	.1169 05	.651 01	.2314 03
.14	.662-03	.694-04	.1179 05	.700 01	.3344 03
.12	.434-03	.503-04	.1188 05	.759 01	.5059 03
.10	.267-03	.258-04	.1198 05	.835 01	.8153 03
.09	.203-03	.176-04	.1202 05	.881 01	.1069 04
.08	.150-03	.116-04	.1207 05	.937 01	.1445 04
.07	.106-03	.718-05	.1211 05	.100 02	.2027 04
.06	.717-04	.415-05	.1216 05	.109 02	.2993 04
.05	.451-04	.217-05	.1220 05	.120 02	.4742 04
.04	.256-04	.987-06	.1225 05	.134 02	.8330 04
.03	.123-04	.355-06	.1229 05	.155 02	.1724 05
.02	.440-05	.845-07	.1233 05	.191 02	.4811 05
.01	.756-06	.840-08	.1238 05	.260 02	.2795 06

Table 23b. EXPANSION AFTER FREEZING - HYPERBOLIC NOZZLE

$T_o' = 5000°K$, $p_o' = 1000$ atm.

$\ell = 0.1$

T	ρ	P	u' (ft/sec.)	M	A
.695	.148 00	.968-01	.9085 04	.219 01	.2265 01
.68	.138 00	.884-01	.9222 04	.232 01	.2390 01
.66	.125 00	.781-01	.9401 04	.241 01	.2576 01
.64	.114 00	.687-01	.9576 04	.249 01	.2785 01
.62	.103 00	.603-01	.9749 04	.257 01	.3023 01
.60	.929-01	.526-01	.9918 04	.266 01	.3293 01
.58	.836-01	.457-01	.1008 05	.275 01	.3602 01
.56	.749-01	.396-01	.1025 05	.284 01	.3957 01
.54	.668-01	.341-01	.1041 05	.294 01	.4365 01
.52	.594-01	.291-01	.1057 05	.304 01	.4837 01
.50	.526-01	.248-01	.1072 05	.315 01	.5387 01
.48	.463-01	.210-01	.1087 05	.326 01	.6030 01
.46	.406-01	.176-01	.1103 05	.337 01	.6787 01
.44	.353-01	.147-01	.1117 05	.349 01	.7686 01
.42	.306-01	.121-01	.1132 05	.362 01	.8759 01
.40	.263-01	.994-02	.1146 05	.376 01	.1005 02
.38	.225-01	.807-02	.1161 05	.390 01	.1162 02
.36	.191-01	.648-02	.1175 05	.405 01	.1355 02
.34	.160-01	.514-02	.1188 05	.422 01	.1593 02
.32	.133-01	.403-02	.1202 05	.439 01	.1893 02
.30	.110-01	.311-02	.1215 05	.459 01	.2273 02
.28	.594-02	.236-02	.1228 05	.479 01	.2764 02
.26	.715-02	.176-02	.1241 05	.502 01	.3406 02
.24	.568-02	.129-02	.1254 05	.527 01	.4263 02
.22	.441-02	.916-03	.1266 05	.555 01	.5431 02
.20	.336-02	.635-03	.1279 05	.587 01	.7061 02
.18	.250-02	.425-03	.1290 05	.623 01	.9399 02
.16	.181-02	.274-03	.1302 05	.665 01	.1287 03
.14	.127-02	.167-03	.1313 05	.714 01	.1824 03
.12	.849-03	.962-04	.1324 05	.775 01	.2700 03
.10	.536-03	.506-04	.1335 05	.852 01	.4239 03
.09	.414-03	.351-04	.1340 05	.899 01	.5473 03
.08	.311-03	.235-04	.1345 05	.955 01	.7259 03
.07	.226-03	.149-04	.1350 05	.102 02	.9966 03
.06	.156-03	.885-05	.1355 05	.111 02	.1434 04
.05	.101-03	.478-05	.1360 05	.122 02	.2201 04
.04	.595-04	.226-05	.1365 05	.137 02	.3718 04
.03	.303-04	.657-06	.1370 05	.158 02	.7315 04
.02	.116-04	.219-06	.1375 05	.195 02	.1901 05
.01	.226-05	.201-07	.1380 05	.281 02	.9753 05

$\ell = 1.0$

T	ρ	P	u' (ft/sec.)	M	A
.575	.415-01	.217-01	.1093 05	.300 01	.6691 01
.56	.381-01	.194-01	.1104 05	.314 01	.7220 01
.54	.338-01	.166-01	.1119 05	.324 01	.8022 01
.52	.299-01	.141-01	.1134 05	.334 01	.8954 01
.50	.263-01	.120-01	.1148 05	.345 01	.1005 02
.48	.230-01	.101-01	.1163 05	.357 01	.1133 02
.46	.201-01	.840-02	.1177 05	.369 01	.1285 02
.44	.174-01	.696-02	.1191 05	.381 01	.1466 02
.42	.150-01	.572-02	.1204 05	.395 01	.1684 02
.40	.128-01	.465-02	.1218 05	.409 01	.1948 02
.38	.109-01	.375-02	.1231 05	.424 01	.2271 02
.36	.914-02	.299-02	.1244 05	.440 01	.2670 02
.34	.762-02	.236-02	.1257 05	.457 01	.3168 02
.32	.629-02	.183-02	.1270 05	.475 01	.3798 02
.30	.514-02	.140-02	.1282 05	.496 01	.4606 02
.28	.415-02	.106-02	.1295 05	.517 01	.5655 02
.26	.330-02	.780-03	.1307 05	.541 01	.7043 02
.24	.258-02	.564-03	.1319 05	.568 01	.8912 02
.22	.199-02	.397-03	.1331 05	.598 01	.1149 03
.20	.150-02	.272-03	.1342 05	.631 01	.1512 03
.18	.110-02	.180-03	.1353 05	.669 01	.2038 03
.16	.786-03	.114-03	.1364 05	.713 01	.2830 03
.14	.542-03	.690-04	.1375 05	.766 01	.4070 03
.12	.358-03	.390-04	.1385 05	.830 01	.6123 03
.10	.222-03	.202-04	.1395 05	.912 01	.9784 03
.09	.170-03	.139-04	.1400 05	.962 01	.1275 04
.08	.126-03	.920-05	.1405 05	.102 02	.1708 04
.07	.908-04	.578-05	.1410 05	.109 02	.2371 04
.06	.622-04	.339-05	.1415 05	.118 02	.3451 04
.05	.398-04	.181-05	.1419 05	.130 02	.5372 04
.04	.231-04	.839-06	.1424 05	.146 02	.9221 04
.03	.115-04	.313-06	.1429 05	.169 02	.1852 05
.02	.428-05	.781-07	.1433 05	.207 02	.4953 05
.01	.790-06	.750-08	.1438 05	.291 02	.2672 06

$\ell = 10$

T	ρ	P	u' (ft/sec.)	M	A
.495	.147-01	.644-02	.1303 05	.362 01	.1716 [illegible]
.48	.133-01	.563-02	.1315 05	.379 01	.1887 [illegible]
.46	.115-01	.465-02	.1327 05	.391 01	.2151 [illegible]
.44	.992-02	.386-02	.1340 05	.404 01	[illegible]
.42	.850-02	.316-02	.1353 05	.418 01	[illegible]
.40	.723-02	.256-02	[illegible]	.432 01	[illegible]
.38	.610-02	[illegible]	[illegible]	.448 01	[illegible]
.36	.511-02	.163-02	.1291 [illegible]	.464 01	[illegible]
.34	.424-02	.127-02	.1304 05	[illegible]	[illegible]
.32	.348-02	.965-03	.1316 05	.501 01	[illegible]
.30	.282-02	.749-03	.1328 05	.522 01	[illegible]
.28	.226-02	.560-03	.1340 05	.545 01	[illegible]
.26	.179-02	.411-03	.1351 05	[illegible]	[illegible]
.24	.139-02	.295-03	.1364 05	.547 01	[illegible]
.22	.106-02	.266-03	.1374 05	.628 01	[illegible]
.20	.791-03	.140-03	.1385 05	[illegible]	[illegible]
.18	.577-03	.918-04	.1396 05	.702 01	[illegible]
.16	.408-03	.578-04	.1407 05	[illegible]	[illegible]
.14	.279-03	.345-04	.1417 05	[illegible]	[illegible]
.12	.182-03	.193-04	.1427 05	.870 01	.1171 [illegible]
.10	.111-03	.986-05	.1437 05	.955 01	[illegible]
.09	.846-04	.674-05	.1442 05	.101 02	[illegible]
.08	.625-04	.442-05	.1446 05	.107 02	[illegible]
.07	.445-04	.276-05	.1451 05	.114 02	[illegible]
.06	.302-04	.160-05	.1455 05	.124 02	[illegible]
.05	.192-04	.847-06	.1460 05	.136 02	.1085 [illegible]
.04	.110-04	.388-06	.1464 05	.152 02	.1886 [illegible]
.03	.527-05	.144-06	.1469 05	.177 02	.3847 [illegible]
.02	.196-05	.352-07	.1473 05	.216 02	[illegible]
.01	.349-06	.250-08	.1478 05	.329 02	.5887 [illegible]

Table 24a. EXPANSION AFTER FREEZING - WEDGE NOZZLE

$T_o' = 6000°K$, $p_o' = 100$ atm.

l = 0.1

T	ρ	P	u' (ft/sec.)	M	A
.73	.198 00	.138 00	.8502 04	.198 01	.1803 01
.72	.190 00	.130 00	.8600 04	.209 01	.1861 01
.70	.174 00	.116 00	.8792 04	.217 01	.1987 01
.68	.159 00	.103 00	.8980 04	.225 01	.2129 01
.66	.145 00	.910-01	.9164 04	.233 01	.2290 01
.64	.131 00	.802-01	.9344 04	.241 01	.2471 01
.62	.119 00	.704-01	.9521 04	.250 01	.2676 01
.60	.108 00	.615-01	.9695 04	.258 01	.2910 01
.58	.969-01	.535-01	.9865 04	.267 01	.3177 01
.56	.869-01	.464-01	.1003 05	.277 01	.3482 01
.54	.776-01	.400-01	.1020 05	.286 01	.3834 01
.52	.691-01	.343-01	.1036 05	.296 01	.4240 01
.50	.612-01	.292-01	.1052 05	.307 01	.4713 01
.48	.540-01	.247-01	.1067 05	.318 01	.5265 01
.46	.474-01	.208-01	.1083 05	.329 01	.5915 01
.44	.414-01	.173-01	.1098 05	.341 01	.6684 01
.42	.359-01	.144-01	.1113 05	.354 01	.7602 01
.40	.309-01	.118-01	.1127 05	.367 01	.8705 01
.38	.265-01	.959-02	.1142 05	.381 01	.1004 02
.36	.225-01	.771-02	.1156 05	.397 01	.1168 02
.34	.189-01	.613-02	.1170 05	.413 01	.1371 02
.32	.158-01	.481-02	.1184 05	.430 01	.1624 02
.30	.130-01	.372-02	.1197 05	.449 01	.1946 02
.28	.106-01	.284-02	.1211 05	.470 01	.2360 02
.26	.855-02	.212-02	.1224 05	.492 01	.2900 02
.24	.678-02	.155-02	.1237 05	.517 01	.3620 02
.22	.528-02	.111-02	.1249 05	.544 01	.4598 02
.20	.404-02	.770-03	.1262 05	.576 01	.5958 02
.18	.301-02	.517-03	.1274 05	.611 01	.7904 02
.16	.219-02	.334-03	.1286 05	.652 01	.1078 03
.14	.154-02	.205-03	.1297 05	.701 01	.1522 03
.12	.103-02	.118-03	.1308 05	.761 01	.2244 03
.10	.656-03	.625-04	.1319 05	.837 01	.3508 03
.09	.507-03	.435-04	.1324 05	.883 01	.4518 03
.08	.382-03	.291-04	.1330 05	.938 01	.5977 03
.07	.278-03	.185-04	.1335 05	.101 02	.8183 03
.06	.193-03	.110-04	.1340 05	.109 02	.1173 04
.05	.126-03	.599-05	.1345 05	.120 02	.1795 04
.04	.745-04	.284-05	.1350 05	.134 02	.3020 04
.03	.379-04	.108-05	.1355 05	.156 02	.5908 04
.02	.146-04	.280-06	.1360 05	.191 02	.1524 05
.01	.288-05	.277-07	.1365 05	.271 02	.7719 05

l = 1.0

T	ρ	P	u' (ft/sec.)	M	A
.63	.780-[illegible]	.455-01	.1010 05	.261 01	.3851 01
.62	.741-01	.425-01	.1019 05	.272 01	.4021 01
.60	.667-01	.371-01	.1035 05	.281 01	.4398 01
.58	.598-01	.321-01	.1051 05	.290 01	.4828 01
.56	.535-01	.277-01	.1066 05	.300 01	.5322 01
.54	.476-01	.238-01	.1082 05	.309 01	.5893 01
.52	.422-01	.203-01	.1097 05	.320 01	.6555 01
.50	.373-01	.172-01	.1112 05	.330 01	.7328 01
.48	.327-01	.145-01	.1127 05	.342 01	.8234 01
.46	.286-01	.122-01	.1141 05	.353 01	.9305 01
.44	.248-01	.101-01	.1156 05	.366 01	.1058 02
.42	.214-01	.834-02	.1170 05	.379 01	.1210 02
.40	.184-01	.681-02	.1184 05	.393 01	.1395 02
.38	.157-01	.551-02	.1197 05	.407 01	.1619 02
.36	.132-01	.441-02	.1211 05	.423 01	.1896 02
.34	.111-01	.349-02	.1224 05	.440 01	.2240 02
.32	.918-02	.272-02	.1237 05	.458 01	.2673 02
.30	.753-02	.209-02	.1250 05	.477 01	.3226 02
.28	.610-02	.158-02	.1263 05	.499 01	.3942 02
.26	.487-02	.117-02	.1275 05	.522 01	.4884 02
.24	.383-02	.852-03	.1288 05	.548 01	.6148 02
.22	.296-02	.604-03	.1300 05	.577 01	.7877 02
.20	.225-02	.416-03	.1312 05	.609 01	.1030 03
.18	.166-02	.277-03	.1323 05	.647 01	.1381 03
.16	.119-02	.177-03	.1334 05	.690 01	.1904 03
.14	.830-03	.108-03	.1345 05	.741 01	.2718 03
.12	.552-03	.613-04	.1356 05	.803 01	.4056 03
.10	.346-03	.320-04	.1366 05	.883 01	.6426 03
.09	.266-03	.221-04	.1371 05	.931 01	.8336 03
.08	.198-03	.147-04	.1376 05	.989 01	.1111 04
.07	.143-03	.929-05	.1381 05	.106 02	.1534 04
.06	.986-04	.548-05	.1386 05	.115 02	.2220 04
.05	.636-04	.294-05	.1391 05	.126 02	.3431 04
.04	.372-04	.138-05	.1396 05	.141 02	.5843 04
.03	.187-04	.519-06	.1401 05	.164 02	.1161 05
.02	.705-05	.131-06	.1405 05	.201 02	.3062 05
.01	.134-05	.126-07	.1410 05	.284 02	.1610 06

l = 10

T	ρ	P	u' (ft/sec.)	M	A
.55	.300-01	.149-01	.1130 05	.319 01	.8957 01
.54	.282-01	.137-01	.1137 05	.331 01	.9455 01
.52	.249-01	.117-01	.1151 05	.341 01	.1057 02
.50	.219-01	.987-02	.1165 05	.352 01	.1188 02
.48	.192-01	.829-02	.1179 05	.364 01	.1342 02
.46	.167-01	.691-02	.1193 05	.376 01	.1525 02
.44	.144-01	.572-02	.1207 05	.389 01	.1743 02
.42	.124-01	.460-02	.1220 05	.402 01	.2006 02
.40	.106-01	.381-02	.1234 05	.416 01	.2325 02
.38	.896-02	.307-02	.1247 05	.432 01	.2716 02
.36	.753-02	.244-02	.1260 05	.448 01	.320[illegible] 02
.34	.627-02	.192-02	.1272 05	.465 01	.3806 02
.32	.517-02	.149-02	.1285 05	.484 01	.4472 02
.30	.421-02	.114-02	.1297 05	.504 01	.5557 02
.28	.339-02	.855-03	.1310 05	.526 01	.6840 02
.26	.269-02	.630-03	.1322 05	.551 01	.8540 02
.24	.210-02	.454-03	.1333 05	.578 01	.1084 03
.22	.161-02	.310-03	.1345 05	.608 01	.1400 03
.20	.121-02	.218-03	.1356 05	.641 01	.1849 03
.18	.887-03	.144-03	.1368 05	.680 01	.2501 03
.16	.632-03	.911-04	.1378 05	.725 01	.3484 03
.14	.434-03	.548-04	.1389 05	.778 01	.5030 03
.12	.286-03	.309-04	.1399 05	.844 01	.7597 03
.10	.177-03	.159-04	.1409 05	.926 01	.1219 04
.09	.135-03	.100-04	.1414 05	.977 01	.1593 04
.08	.100-03	.721-05	.1419 05	.104 02	.2139 04
.07	.716-04	.451-05	.1424 05	.111 02	.2978 04
.06	.489-04	.264-05	.1428 05	.120 02	.4348 04
.05	.312-04	.140-05	.1433 05	.132 02	.6790 04
.04	.180-04	.650-06	.1437 05	.148 02	.1171 05
.03	.891-05	.239-06	.1442 05	.171 02	.2363 05
.02	.330-05	.605-07	.1447 05	.210 02	.6368 05
.01	.601-06	.500-08	.1451 05	.305 02	.3481 06

Table 24b. EXPANSION AFTER FREEZING - HYPERBOLIC NOZZLE

$T_o' = 6000°K$, $p_o' = 100$ atm.

ℓ = 0.1

T	ρ	P	u' (ft/sec.)	M	A
.609	.650-01	.367-01	.1020 05	.273 01	.4501 01
.60	.619-01	.344-01	.1027 05	.280 01	.4696 01
.58	.553-01	.297-01	.1043 05	.289 01	.5176 01
.56	.492-01	.255-01	.1059 05	.299 01	.5729 01
.54	.436-01	.218-01	.1075 05	.309 01	.6370 01
.52	.385-01	.186-01	.1090 05	.319 01	.7117 01
.50	.338-01	.157-01	.1105 05	.330 01	.7992 01
.48	.296-01	.132-01	.1120 05	.341 01	.9022 01
.46	.257-01	.110-01	.1134 05	.352 01	.1025 02
.44	.222-01	.906-02	.1148 05	.365 01	.1171 02
.42	.191-01	.742-02	.1163 05	.378 01	.1347 02
.40	.163-01	.603-02	.1177 05	.392 01	.1560 02
.38	.135-01	.485-02	.1190 05	.406 01	.1822 02
.36	.116-01	.386-02	.1204 05	.422 01	.2147 02
.34	.961-02	.303-02	.1217 05	.439 01	.2553 02
.32	.791-02	.235-02	.1230 05	.457 01	.3068 02
.30	.644-02	.179-02	.1243 05	.477 01	.3729 02
.28	.512-02	.134-02	.1256 05	.498 01	.4591 02
.26	.410-02	.989-03	.1268 05	.521 01	.5734 02
.24	.320-02	.713-03	.1281 05	.547 01	.7279 02
.22	.245-02	.530-03	.1293 05	.576 01	.9413 02
.20	.184-02	.341-03	.1305 05	.609 01	.1243 03
.18	.135-02	.225-03	.1316 05	.646 01	.1684 03
.16	.956-03	.142-03	.1327 05	.689 01	.2348 03
.14	.657-03	.653-04	.1338 05	.740 01	.3393 03
.12	.431-03	.480-04	.1349 05	.802 01	.5132 03
.10	.266-03	.247-04	.1359 05	.881 01	.8249 03
.09	.203-03	.169-04	.1364 05	.929 01	.1079 04
.08	.150-03	.112-04	.1369 05	.987 01	.1450 04
.07	.108-03	.698-05	.1374 05	.106 02	.2020 04
.06	.733-04	.408-05	.1379 05	.114 02	.2953 04
.05	.467-04	.227-05	.1384 05	.126 02	.4618 04
.04	.270-04	.100-05	.1389 05	.141 02	.7974 04
.03	.133-04	.370-06	.1393 05	.163 02	.1613 05
.02	.490-05	.912-07	.1398 05	.200 02	.4362 05
.01	.888-06	.780-08	.1403 05	.289 02	.2396 06

ℓ = 1.0

T	ρ	P	u' (ft/sec.)	M	A
.514	.230-01	.107-01	.1141 05	.336 01	.1138 02
.50	.209-01	.950-02	.1151 05	.348 01	.1238 02
.48	.182-01	.794-02	.1165 05	.360 01	.1404 02
.46	.158-01	.659-02	.1179 05	.372 01	.1602 02
.44	.136-01	.543-02	.1193 05	.384 01	.1839 02
.42	.116-01	.443-02	.1206 05	.398 01	.2126 02
.40	.989-02	.359-02	.1220 05	.412 01	.2475 02
.38	.833-02	.287-02	.1233 05	.427 01	.2906 02
.36	.696-02	.227-02	.1246 05	.443 01	.3441 02
.34	.577-02	.178-02	.1259 05	.460 01	.4114 02
.32	.472-02	.137-02	.1271 05	.479 01	.4971 02
.30	.383-02	.104-02	.1284 05	.499 01	.6077 02
.28	.306-02	.777-03	.1296 05	.521 01	.7528 02
.26	.241-02	.568-03	.1308 05	.545 01	.9463 02
.24	.187-02	.407-03	.1320 05	.572 01	.1209 03
.22	.142-02	.284-03	.1332 05	.602 01	.1575 03
.20	.106-02	.192-03	.1343 05	.635 01	.2096 03
.18	.770-03	.126-03	.1354 05	.674 01	.2862 03
.16	.543-03	.788-04	.1365 05	.718 01	.4025 03
.14	.370-03	.469-04	.1376 05	.771 01	.5870 03
.12	.240-03	.261-04	.1386 05	.836 01	.8956 03
.10	.147-03	.133-04	.1396 05	.918 01	.1457 04
.09	.111-03	.908-05	.1401 05	.968 01	.1916 04
.08	.819-04	.594-05	.1406 05	.103 02	.2592 04
.07	.582-04	.370-05	.1410 05	.110 02	.3635 04
.06	.394-04	.214-05	.1415 05	.119 02	.5354 04
.05	.249-04	.113-05	.1420 05	.131 02	.8445 04
.04	.142-04	.516-06	.1424 05	.147 02	.1473 05
.03	.692-05	.188-06	.1429 05	.170 02	.3020 05
.02	.251-05	.442-07	.1434 05	.210 02	.8314 05
.01	.441-06	.520-08	.1438 05	.277 02	.4710 06

ℓ = 10

T	ρ	P	u' (ft/sec.)	M	A
.44	.990-02	.390-02	.1217 05	.386 01	.2478 02
.42	.845-02	.318-02	.1230 05	.408 01	.2872 02
.40	.716-02	.257-02	.1243 05	.423 01	.3353 02
.38	.602-02	.205-02	.1256 05	.438 01	.3946 02
.36	.502-02	.162-02	.1269 05	.454 01	.4685 02
.34	.415-02	.126-02	.1281 05	.472 01	.5617 02
.32	.339-02	.972-03	.1294 05	.491 01	.6808 02
.30	.274-02	.736-03	.1306 05	.511 01	.8349 02
.28	.218-02	.546-03	.1318 05	.534 01	.1038 03
.26	.172-02	.400-03	.1330 05	.558 01	.1300 03
.24	.133-02	.285-03	.1342 05	.586 01	.1678 03
.22	.101-02	.198-03	.1353 05	.616 01	.2194 03
.20	.746-03	.134-03	.1364 05	.650 01	.2932 03
.18	.540-03	.872-04	.1375 05	.689 01	.4019 03
.16	.379-03	.544-04	.1386 05	.735 01	.5677 03
.14	.257-03	.322-04	.1396 05	.788 01	.8321 03
.12	.166-03	.179-04	.1406 05	.854 01	.1278 04
.10	.101-03	.905-05	.1416 05	.938 01	.2088 04
.09	.763-04	.615-05	.1421 05	.989 01	.2754 04
.08	.560-04	.402-05	.1426 05	.105 02	.3738 04
.07	.397-04	.249-05	.1430 05	.112 02	.5261 04
.06	.267-04	.144-05	.1435 05	.122 02	.7780 04
.05	.168-04	.753-06	.1439 05	.133 02	.1233 05
.04	.956-05	.344-06	.1444 05	.150 02	.2162 05
.03	.462-05	.125-06	.1449 05	.173 02	.4461 05
.02	.166-05	.286-07	.1453 05	.214 02	.1240 06
.01	.287-06	.260-08	.1457 05	.303 02	.7140 06

Table 25a. EXPANSION AFTER FREEZING - WEDGE NOZZLE

$T_o' = 6000°K$, $p_o' = 300$ atm.

l = 0.1

T	ρ	P	u' (ft/sec.)	M	A
.663	.110 00	.684-01	.9440 04	.239 01	.2875 01
.66	.109 00	.673-01	.9462 04	.244 01	.2904 01
.64	.982-01	.590-01	.9635 04	.252 01	.3155 01
.62	.885-01	.515-01	.9806 04	.261 01	.3440 01
.60	.795-01	.448-01	.9973 04	.270 01	.3767 01
.58	.711-01	.387-01	.1014 05	.279 01	.4141 01
.56	.634-01	.333-01	.1030 05	.288 01	.4571 01
.54	.563-01	.285-01	.1046 05	.298 01	.5070 01
.52	.498-01	.243-01	.1062 05	.308 01	.5649 01
.50	.438-01	.206-01	.1077 05	.319 01	.6327 01
.48	.384-01	.173-01	.1092 05	.330 01	.7124 01
.46	.334-01	.144-01	.1107 05	.341 01	.8068 01
.44	.289-01	.120-01	.1122 05	.354 01	.9193 01
.42	.249-01	.982-02	.1136 05	.366 01	.1055 02
.40	.213-01	.800-02	.1151 05	.380 01	.1218 02
.38	.181-01	.645-02	.1165 05	.394 01	.1419 02
.36	.152-01	.514-02	.1178 05	.410 01	.1666 02
.36	.152-01	.514-02	.1178 05	.410 01	.1666 02
.34	.127-01	.405-02	.1192 05	.426 01	.1975 02
.34	.127-01	.405-02	.1192 05	.426 01	.1975 02
.32	.105-01	.314-02	.1205 05	.444 01	.2366 02
.30	.855-02	.241-02	.1219 05	.464 01	.2866 02
.28	.689-02	.181-02	.1232 05	.484 01	.3517 02
.26	.548-02	.134-02	.1245 05	.507 01	.4376 02
.24	.429-02	.967-03	.1257 05	.533 01	.5534 02
.22	.330-02	.662-03	.1269 05	.561 01	.7127 02
.20	.246-02	.467-03	.1281 05	.593 01	.9374 02
.18	.183-02	.309-03	.1293 05	.629 01	.1264 03
.18	.183-02	.309-03	.1293 05	.629 01	.1264 03
.16	.130-02	.196-03	.1305 05	.671 01	.1754 03
.14	.900-03	.118-03	.1316 05	.721 01	.2521 03
.12	.593-03	.669-04	.1327 05	.783 01	.3792 03
.10	.369-03	.346-04	.1337 05	.860 01	.6057 03
.09	.282-03	.238-04	.1342 05	.907 01	.7895 03
.09	.282-03	.238-04	.1342 05	.907 01	.7895 03
.08	.209-03	.157-04	.1347 05	.964 01	.1057 04
.07	.150-03	.988-05	.1352 05	.103 02	.1468 04
.06	.103-03	.580-05	.1357 05	.112 02	.2137 04
.05	.659-04	.309-05	.1362 05	.123 02	.3326 04
.04	.382-04	.144-05	.1367 05	.138 02	.5711 04
.03	.190-04	.534-06	.1372 05	.160 02	.1147 05
.02	.706-05	.133-06	.1377 05	.196 02	.3071 05
.01	.130-05	.130-07	.1382 05	.274 02	.1658 06

l = 1.0

T	ρ	P	u' (ft/sec.)	M	A
.575	.45[illegible]	.238-01	.1066 05	.295 01	.6221 01
.56	.412-[illegible]	.212-01	.1078 05	.306 01	.6724 01
.54	.365-01	.181-01	.1093 05	.316 01	.7490 01
.54	.365-01	.181-01	.1093 05	.316 01	.7490 01
.52	.321-01	.154-01	.1108 05	.326 01	.8382 01
.50	.282-01	.130-01	.1123 05	.337 01	.9429 01
.48	.246-01	.109-01	.1137 05	.348 01	.1066 02
.46	.214-01	.903-02	.1152 05	.360 01	.1213 02
.44	.184-01	.745-02	.1166 05	.372 01	.1389 02
.42	.158-01	.610-02	.1180 05	.386 01	.1601 02
.40	.135-01	.495-02	.1193 05	.400 01	.1859 02
.38	.114-01	.397-02	.1207 05	.414 01	.2175 02
.36	.953-02	.315-02	.1220 05	.430 01	.2567 02
.34	.791-02	.247-02	.1233 05	.447 01	.3060 02
.32	.650-02	.191-02	.1246 05	.466 01	.3685 02
.30	.528-02	.146-02	.1259 05	.485 01	.4489 02
.28	.424-02	.109-02	.1272 05	.507 01	.5541 02
.26	.335-02	.801-03	.1284 05	.531 01	.6938 02
.24	.261-02	.575-03	.1296 05	.557 01	.8832 02
.22	.199-02	.403-03	.1308 05	.586 01	.1145 03
.20	.149-02	.274-03	.1320 05	.619 01	.1518 03
.18	.109-02	.180-03	.1331 05	.657 01	.2061 03
.16	.771-03	.113-03	.1342 05	.700 01	.2885 03
.14	.527-03	.678-04	.1353 05	.752 01	.4185 03
.12	.345-03	.380-04	.1363 05	.815 01	.6354 03
.10	.212-03	.195-04	.1374 05	.896 01	.1026 04
.09	.161-03	.133-04	.1379 05	.944 01	.1344 04
.08	.119-03	.876-05	.1383 05	.100 02	.1812 04
.07	.850-04	.546-05	.1388 05	.107 02	.2531 04
.06	.577-04	.318-05	.1393 05	.116 02	.3711 04
.05	.367-04	.168-05	.1398 05	.128 02	.5825 04
.04	.211-04	.774-06	.1402 05	.143 02	.1010 05
.03	.103-04	.284-06	.1407 05	.166 02	.2054 05
.02	.378-05	.703-07	.1412 05	.204 02	.5597 05
.01	.677-06	.520-08	.1416 05	.304 02	.3114 06

l = 10

T	ρ	P	u' (ft/sec.)	M	A
.502	.200-01	.908-02	.1154 05	.343 01	.1293 02
.50	.197-01	.892-02	.1156 05	.350 01	.1309 02
.48	.172-01	.746-02	.1170 05	.362 01	.1485 02
.46	.149-01	.619-02	.1184 05	.374 01	.1695 02
.44	.128-01	.510-02	.1197 05	.386 01	.1947 02
.42	.109-01	.416-02	.1211 05	.400 01	.2252 02
.40	.929-02	.336-02	.1224 05	.414 01	.2623 02
.38	.783-02	.269-02	.1238 05	.429 01	.3091 02
.36	.654-02	.213-02	.1250 05	.445 01	.3650 02
.34	.541-02	.166-02	.1263 05	.463 01	.4367 02
.32	.443-02	.128-02	.1276 05	.481 01	.5280 02
.30	.359-02	.973-03	.1288 05	.502 01	.6[illegible] 02
.28	.287-02	.726-03	.1301 05	.524 01	.8006 02
.26	.226-02	.531-03	.1313 05	.549 01	.1007 03
.24	.175-02	.380-03	.1324 05	.575 01	.1288 03
.22	.133-02	.265-03	.1336 05	.605 01	.1679 03
.20	.990-03	.179-03	.1347 05	.638 01	.2237 03
.18	.719-03	.117-03	.1359 05	.677 01	.3056 03
.16	.507-03	.733-04	.1369 05	.722 01	.4303 03
.14	.344-03	.436-04	.1380 05	.775 01	.6283 03
.12	.223-03	.243-04	.1390 05	.840 01	.9607 03
.10	.136-03	.123-04	.1400 05	.922 01	.1563 04
.09	.103-03	.841-05	.1405 05	.972 01	.2057 04
.08	.760-04	.550-05	.1410 05	.103 02	.2784 04
.07	.540-04	.342-05	.1414 05	.111 02	.3908 04
.06	.365-04	.198-05	.1419 05	.120 02	.5761 04
.05	.230-04	.104-05	.1424 05	.131 02	.9097 04
.04	.132-04	.477-06	.1428 05	.147 02	.1589 05
.03	.639-05	.175-06	.1433 05	.170 02	.3261 05
.02	.231-05	.416-07	.1437 05	.209 02	.8998 05
.01	.405-06	.260-08	.1442 05	.330 02	.5113 06

Table 25b. EXPANSION AFTER FREEZING - HYPERBOLIC NOZZLE

T_o' = 6000°K, p_o' = 300 atm.

$\ell = 0.1$

T	ρ	P	u' (ft/sec.)	M	A
.533	.370-01	.184-01	.1073 05	.309 01	.7388 01
.52	.340-01	.165-01	.1082 05	.317 01	.7966 01
.50	.297-01	.139-01	.1097 05	.328 01	.8983 01
.48	.259-01	.116-01	.1112 05	.339 01	.1019 02
.46	.224-01	.961-02	.1127 05	.350 01	.1162 02
.44	.193-01	.791-02	.1141 05	.363 01	.1334 02
.42	.164-01	.645-02	.1155 05	.376 01	.1543 02
.40	.140-01	.521-02	.1169 05	.390 01	.1797 02
.38	.117-01	.416-02	.1183 05	.404 01	.2110 02
.36	.980-02	.329-02	.1197 05	.420 01	.2501 02
.34	.810-02	.257-02	.1210 05	.437 01	.2992 02
.32	.662-02	.198-02	.1223 05	.455 01	.3618 02
.30	.536-02	.150-02	.1236 05	.474 01	.4428 02
.28	.428-02	.112-02	.1249 05	.496 01	.5491 02
.26	.336-02	.816-03	.1261 05	.519 01	.6911 02
.24	.260-02	.582-03	.1274 05	.545 01	.8845 02
.22	.195-02	.406-03	.1286 05	.573 01	.1154 03
.20	.147-02	.274-03	.1298 05	.606 01	.1538 03
.18	.105-02	.179-03	.1309 05	.643 01	.2104 03
.16	.749-03	.112-03	.1320 05	.686 01	.2965 03
.14	.503-03	.564-04	.1331 05	.736 01	.4336 03
.12	.329-03	.368-04	.1342 05	.798 01	.6640 03
.10	.200-03	.187-04	.1352 05	.877 01	.1082 04
.09	.152-03	.127-04	.1357 05	.925 01	.1426 04
.08	.111-03	.332-05	.1362 05	.983 01	.1932 04
.07	.790-04	.515-05	.1367 05	.105 02	.2715 04
.06	.533-04	.299-05	.1372 05	.114 02	.4008 04
.05	.336-04	.157-05	.1377 05	.125 02	.6339 04
.04	.191-04	.713-06	.1381 05	.140 02	.1109 05
.03	.927-05	.259-06	.1386 05	.163 02	.2283 05
.02	.333-05	.621-07	.1391 05	.200 02	.6324 05
.01	.581-06	.540-08	.1395 05	.284 02	.3616 06

$\ell = 1.0$

T	ρ	P	u' (ft/sec.)	M	A
.451	.165-01	.690-02	.1152 05	.359 01	.1542 02
.44	.152-01	.618-02	.1160 05	.370 01	.1667 02
.42	.129-01	.504-02	.1174 05	.383 01	.1930 02
.40	.110-01	.406-02	.1188 05	.397 01	.2252 02
.38	.921-02	.325-02	.1201 05	.412 01	.2649 02
.36	.768-02	.256-02	.1214 05	.428 01	.3144 02
.34	.634-02	.200-02	.1228 05	.445 01	.3769 02
.32	.518-02	.154-02	.1241 05	.463 01	.4566 02
.30	.418-02	.116-02	.1253 05	.483 01	.5599 02
.28	.333-02	.864-03	.1266 05	.504 01	.6957 02
.26	.261-02	.630-03	.1278 05	.528 01	.8774 02
.24	.202-02	.449-03	.1290 05	.554 01	.1125 03
.22	.153-02	.312-03	.1302 05	.563 01	.1471 03
.20	.113-02	.210-03	.1314 05	.616 01	.1966 03
.18	.820-03	.137-03	.1325 05	.653 01	.2696 03
.16	.576-03	.854-04	.1336 05	.697 01	.3811 03
.14	.389-03	.505-04	.1347 05	.748 01	.5568 03
.12	.252-03	.280-04	.1358 05	.811 01	.8585 03
.10	.153-03	.142-04	.1368 05	.891 01	.1404 04
.09	.115-03	.961-05	.1373 05	.939 01	.1853 04
.08	.846-04	.627-05	.1378 05	.998 01	.2516 04
.07	.599-04	.388-05	.1382 05	.107 02	.3543 04
.06	.403-04	.224-05	.1387 05	.116 02	.5243 04
.05	.253-04	.118-05	.1392 05	.127 02	.8313 04
.04	.144-04	.532-06	.1397 05	.142 02	.1459 05
.03	.694-05	.192-06	.1401 05	.165 02	.3015 05
.02	.246-05	.459-07	.1406 05	.203 02	.8397 05
.01	.429-06	.270-08	.1410 05	.324 02	.4847 06

$\ell = 10$

T	ρ	P	u' (ft/sec.)	M	A
.394	.920-02	.335-02	.1199 05	.397 01	.2658 02
.38	.814-02	.286-02	.1208 05	.415 01	[illegible]
.36	.678-02	.226-02	.1222 05	.431 01	[illegible]
.34	.559-02	.176-02	.1235 05	.448 01	[illegible]
.32	.456-02	.135-02	.1248 05	.466 01	.5140 02
.30	.368-02	.102-02	.1260 05	.486 01	.6318 02
.28	.293-02	.759-03	.1273 05	.508 01	[illegible]
.26	.230-02	.553-03	.1285 05	.532 01	[illegible]
.24	.178-02	.394-03	.1297 05	.558 01	[illegible]
.22	.135-02	.274-03	.1309 05	.587 01	.1665 03
.20	.997-03	.184-03	.1321 05	.620 01	.2227 03
.18	.720-03	.120-03	.1332 05	.658 01	.3057 03
.16	.505-03	.747-04	.1343 05	.701 01	[illegible]
.14	.341-03	.442-04	.1354 05	[illegible]	[illegible]
.12	.220-03	.244-04	.1364 05	.816 01	[illegible]
.10	.133-03	.123-04	.1374 05	.897 01	[illegible]
.09	.101-03	.838-05	.1379 05	.945 01	.2111 04
.08	.739-04	.546-05	.1384 05	.100 02	.2869 04
.07	.522-04	.338-05	.1389 05	.108 02	[illegible]
.06	.351-04	.195-05	.1393 05	.116 02	[illegible]
.05	.221-04	.102-05	.1398 05	.128 02	[illegible]
.04	.125-04	.462-06	.1403 05	.143 02	.1670 05
.03	.603-05	.167-06	.1407 05	.166 02	[illegible]
.02	.215-05	.405-07	.1412 05	.203 02	[illegible]
.01	.370-06	.270-08	.1417 05	.310 02	[illegible]

Table 26a. EXPANSION AFTER FREEZING - WEDGE NOZZLE

$T_o' = 6000°K$, $p_o' = 1000$ atm.

ℓ = 0.1

T	ρ	P	u' (ft/sec.)	M	A
.591	.643-01	.357-01	.1006 05	.274 01	.4532 01
.58	.603-01	.329-01	.1015 05	.280 01	.4789 01
.56	.535-01	.282-01	.1031 05	.289 01	.5312 01
.54	.473-01	.240-01	.1047 05	.299 01	.5920 01
.52	.416-01	.204-01	.1062 05	.309 01	.6629 01
.50	.365-01	.171-01	.1078 05	.320 01	.7463 01
.48	.318-01	.143-01	.1093 05	.331 01	.8448 01
.46	.275-01	.119-01	.1108 05	.343 01	.9621 01
.44	.237-01	.981-02	.1122 05	.355 01	.1103 02
.42	.203-01	.801-02	.1137 05	.368 01	.1273 02
.40	.172-01	.648-02	.1151 05	.382 01	.1480 02
.38	.145-01	.519-02	.1165 05	.396 01	.1734 02
.36	.121-01	.411-02	.1179 05	.412 01	.2051 02
.34	.100-01	.321-02	.1192 05	.428 01	.2449 02
.32	.823-02	.248-02	.1206 05	.446 01	.2955 02
.30	.667-02	.188-02	.1219 05	.465 01	.3608 02
.28	.533-02	.140-02	.1232 05	.486 01	.4465 02
.26	.420-02	.103-02	.1245 05	.509 01	.5606 02
.24	.326-02	.736-03	.1257 05	.535 01	.7157 02
.22	.248-02	.513-03	.1269 05	.563 01	.9311 02
.20	.185-02	.348-03	.1281 05	.595 01	.1238 03
.18	.134-02	.227-03	.1293 05	.631 01	.1688 03
.16	.948-03	.143-03	.1304 05	.674 01	.2372 03
.14	.645-03	.849-04	.1315 05	.724 01	.3457 03
.12	.419-03	.473-04	.1326 05	.785 01	.5275 03
.10	.256-03	.241-04	.1337 05	.863 01	.8563 03
.09	.194-03	.164-04	.1342 05	.910 01	.1126 04
.08	.143-03	.108-04	.1347 05	.967 01	.1522 04
.07	.102-03	.689-05	.1352 05	.104 02	.2134 04
.06	.688-04	.388-05	.1356 05	.112 02	.3141 04
.05	.435-04	.205-05	.1361 05	.123 02	.4952 04
.04	.249-04	.935-06	.1366 05	.138 02	.8634 04
.03	.121-04	.340-06	.1371 05	.160 02	.1769 05
.02	.438-05	.810-07	.1376 05	.197 02	.4867 05
.01	.771-06	.810-08	.1380 05	.271 02	.2756 06

ℓ = 1.0

T	ρ	P	u' (ft/sec.)	M	A
.513	.302-01	.144-01	.1094 05	.320 01	.8874 01
.50	.278-01	.129-01	.1103 05	.330 01	.9576 01
.48	.241-01	.108-01	.1118 05	.341 01	.1086 02
.46	.209-01	.894-02	.1133 05	.353 01	.1240 02
.44	.179-01	.735-02	.1147 05	.365 01	.1424 02
.42	.153-01	.599-02	.1161 05	.378 01	.1648 02
.40	.130-01	.484-02	.1175 05	.392 01	.1920 02
.38	.109-01	.387-02	.1188 05	.407 01	.2256 02
.36	.912-02	.306-02	.1202 05	.422 01	.2675 02
.34	.753-02	.239-02	.1215 05	.439 01	.3202 02
.32	.616-02	.184-02	.1228 05	.457 01	.3875 02
.30	.498-02	.139-02	.1241 05	.477 01	.4745 02
.28	.397-02	.104-02	.1254 05	.498 01	.5888 02
.26	.312-02	.756-03	.1266 05	.522 01	.7415 02
.24	.241-02	.540-03	.1279 05	.547 01	.9497 02
.22	.183-02	.375-03	.1291 05	.576 01	.1240 03
.20	.136-02	.253-03	.1302 05	.609 01	.1654 03
.18	.986-03	.165-03	.1314 05	.646 01	.2264 03
.16	.693-03	.103-03	.1325 05	.689 01	.3194 03
.14	.469-03	.612-04	.1336 05	.740 01	.4674 03
.12	.304-03	.340-04	.1347 05	.802 01	.7165 03
.10	.185-03	.172-04	.1357 05	.882 01	.1169 04
.09	.140-03	.117-04	.1362 05	.929 01	.1541 04
.08	.103-03	.765-05	.1367 05	.987 01	.2089 04
.07	.727-04	.474-05	.1372 05	.106 02	.2938 04
.06	.491-04	.274-05	.1376 05	.114 02	.4341 04
.05	.309-04	.144-05	.1381 05	.126 02	.6870 04
.04	.176-04	.654-06	.1386 05	.141 02	.1203 05
.03	.850-05	.238-06	.1391 05	.163 02	.2480 05
.02	.306-05	.567-07	.1395 05	.201 02	.6879 05
.01	.530-06	.540-08	.1400 05	.277 02	.3953 06

ℓ = 10

T	ρ	P	u' (ft/sec.)	M	A
.441	.149-01	.609-02	.1161 05	.366 01	.1695 02
.44	.148-01	.603-02	.1162 05	.371 01	.1707 02
.42	.126-01	.491-02	.1175 05	.384 01	.1977 02
.40	.107-01	.396-02	.1189 05	.398 01	.2307 02
.38	.898-02	.316-02	.1203 05	.413 01	.2715 02
.36	.748-02	.249-02	.1216 05	.429 01	.3223 02
.34	.617-02	.194-02	.1229 05	.446 01	.3864 02
.32	.504-02	.149-02	.1242 05	.464 01	[illegible] 02
.30	.407-02	.113-02	.1255 05	.484 01	.5742 02
.28	.324-02	.841-03	.1267 05	.505 01	.7136 02
.26	.254-02	.613-03	.1280 05	.529 01	[illegible] 02
.24	.197-02	.437-03	.1292 05	.555 01	.1155 03
.22	.149-02	.303-03	.1304 05	.584 01	.1510 03
.20	.110-02	.205-03	.1315 05	.617 01	.2016 03
.18	.798-03	.133-03	.1327 05	.654 01	.2769 03
.16	.560-03	.830-04	.1338 05	.698 01	.3915 03
.14	.379-03	.491-04	.1349 05	.749 01	.5742 03
.12	.244-03	.272-04	.1359 05	.812 01	.8825 03
.10	.148-03	.137-04	.1369 05	.892 01	.1444 04
.09	.112-03	.933-05	.1374 05	.941 01	.1905 04
.08	.821-04	.609-05	.1379 05	.999 01	.2588 04
.07	.581-04	.377-05	.1384 05	.107 02	.3646 04
.06	.391-04	.217-05	.1388 05	.116 02	.5397 04
.05	.246-04	.114-05	.1393 05	.127 02	.8560 04
.04	.140-04	.516-06	.1398 05	.143 02	.1503 05
.03	.673-05	.186-06	.1402 05	.165 02	.3106 05
.02	.241-05	.432-07	.1407 05	.204 02	.8661 05
.01	.415-06	.270-08	.1412 05	.324 02	.5008 06

Table 26b. EXPANSION AFTER FREEZING - HYPERBOLIC NOZZLE

$T_o' = 6000°K$, $p_o' = 1000$ atm.

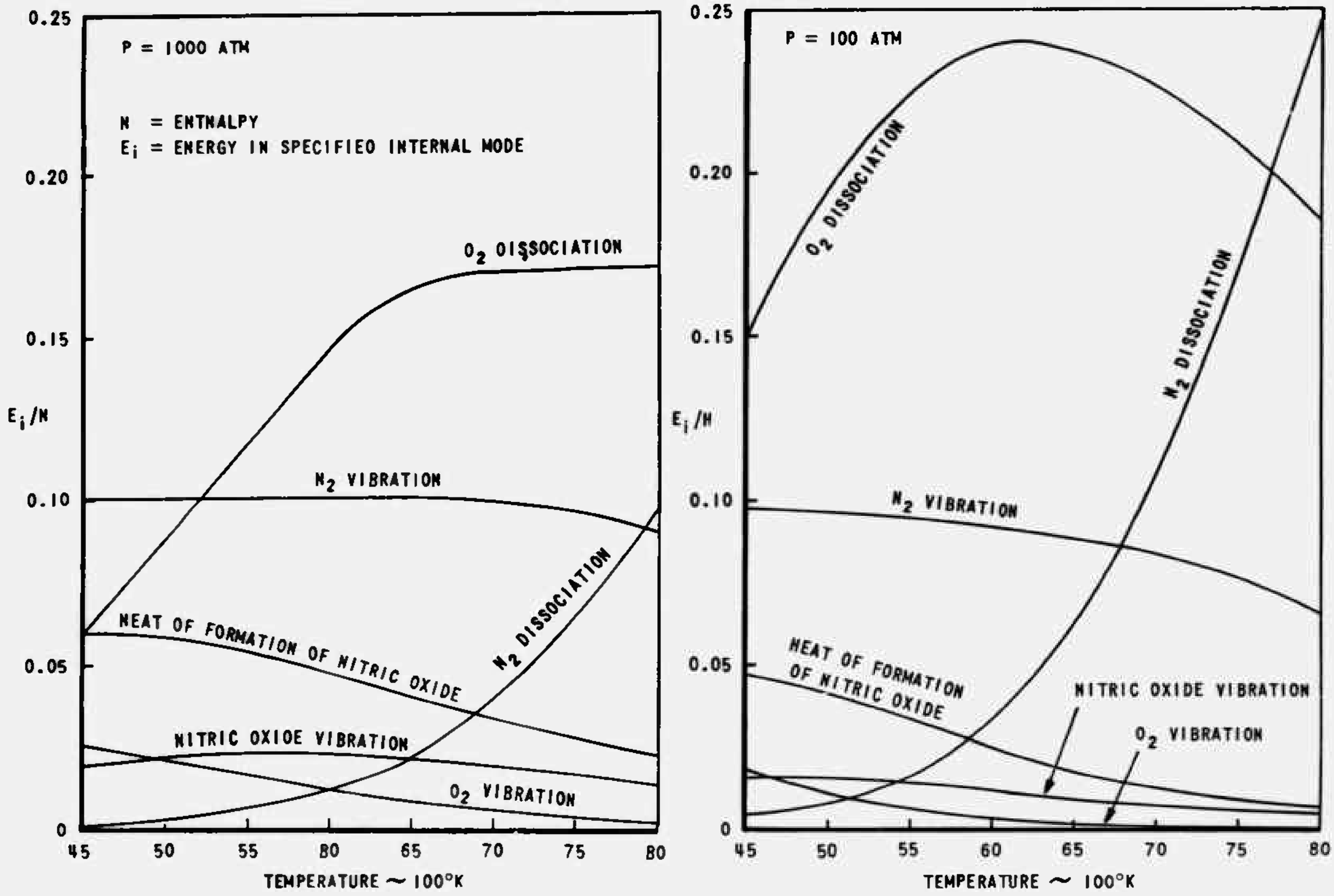
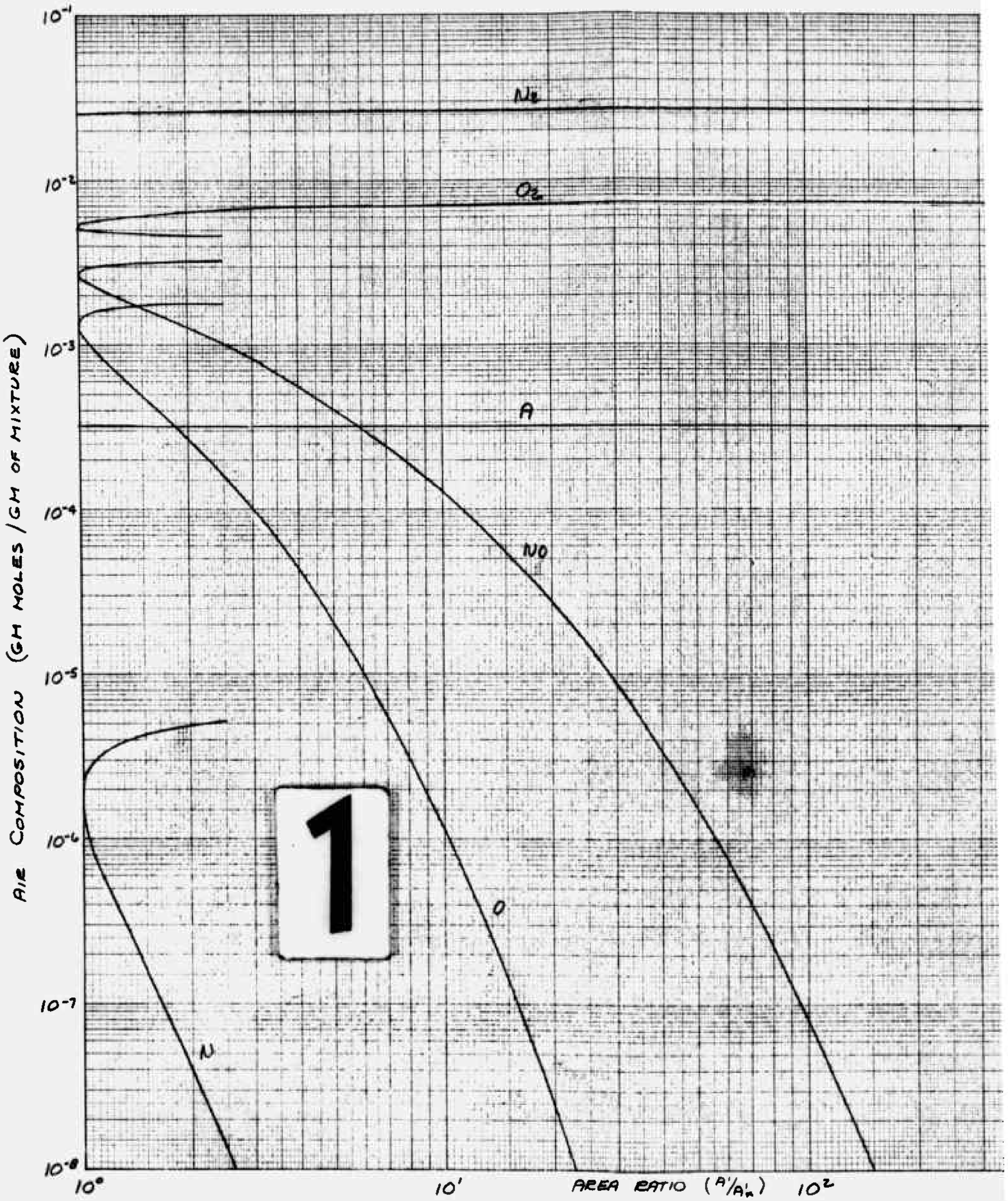
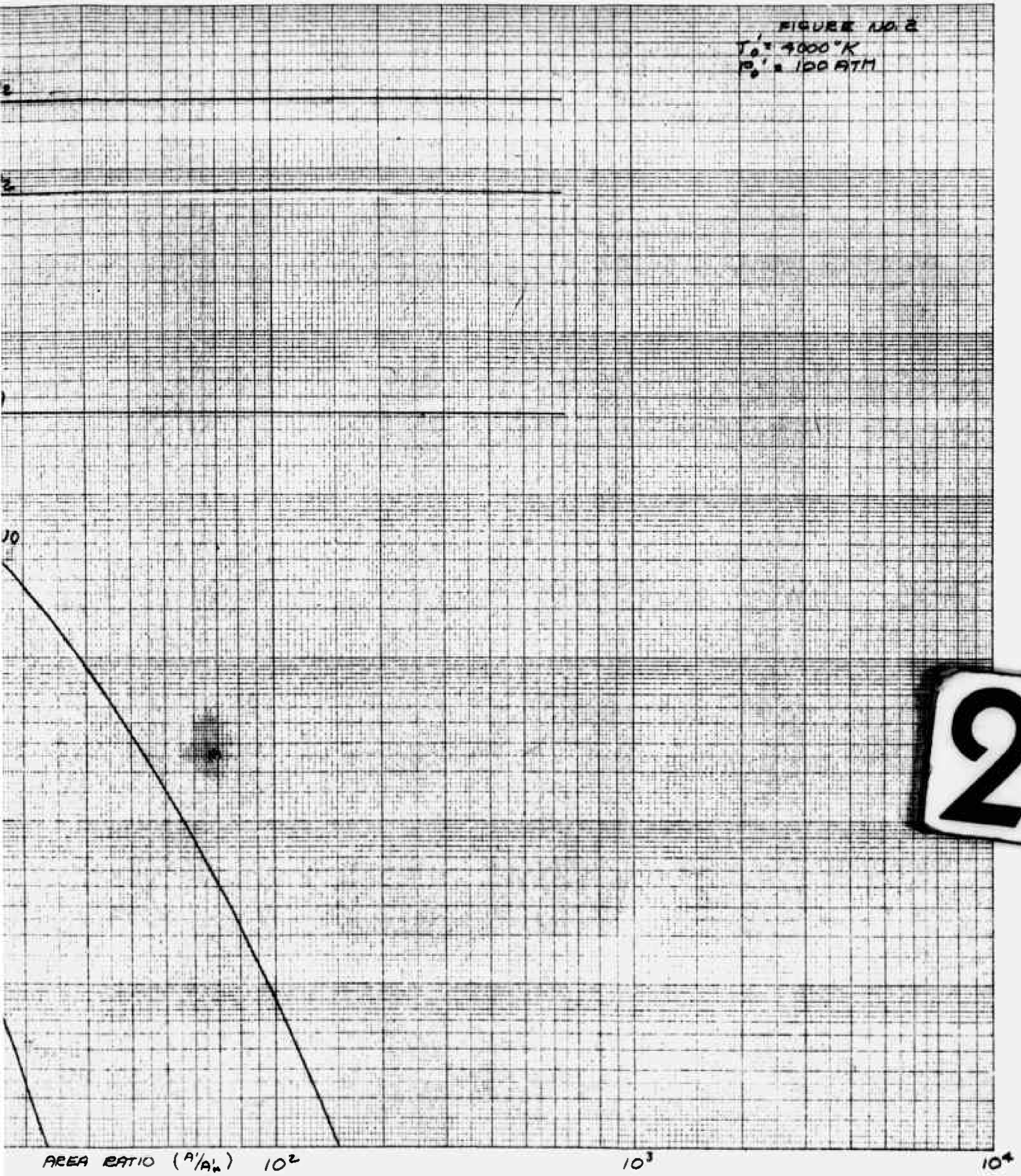


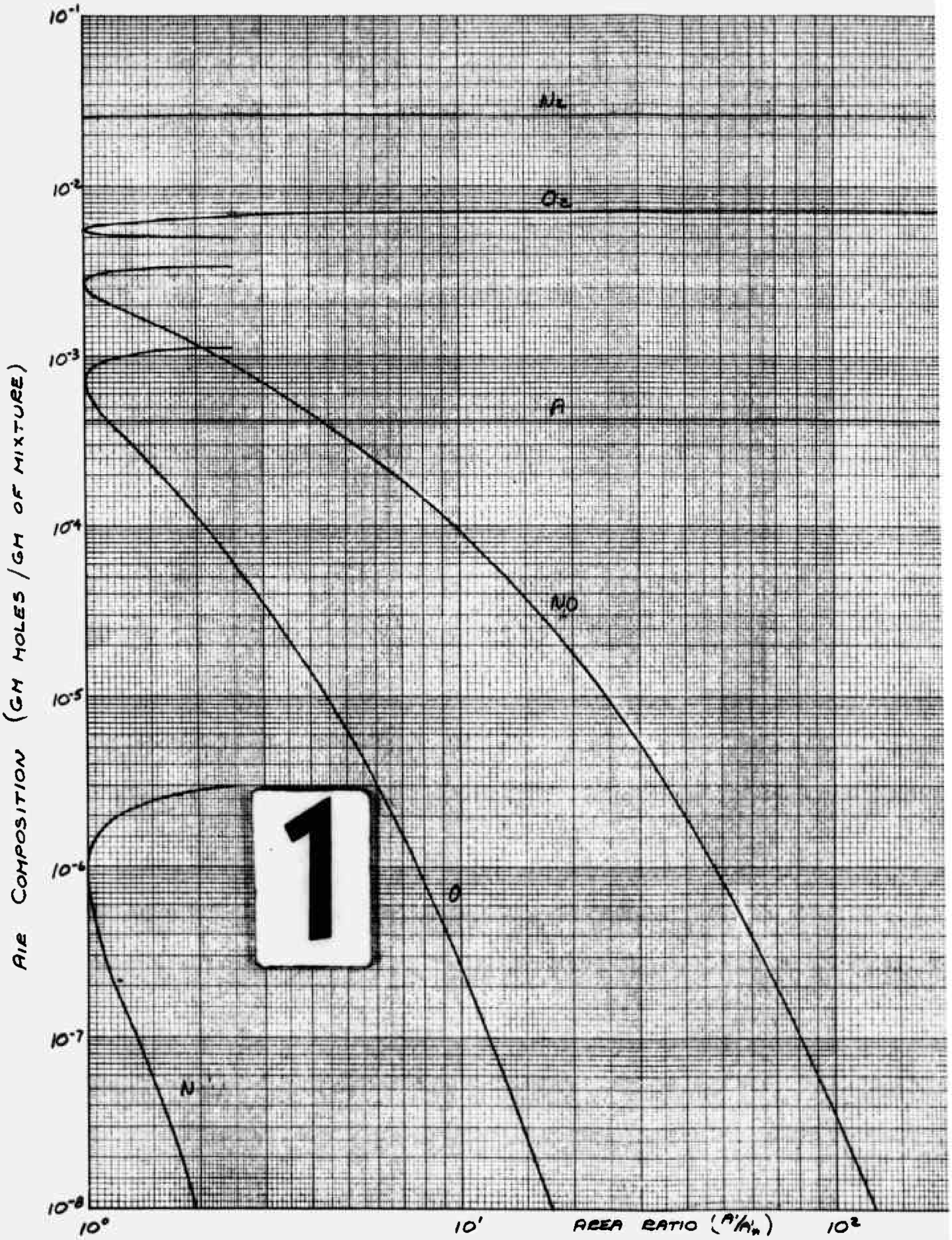
Figure 1 FRACTION OF THE ENTHALPY OF EQUILIBRIUM AIR WHICH IS IN THE SPECIFIED ENERGY MODE
(REFERENCE: CAL REPORT NO. BE-1007-A-3)



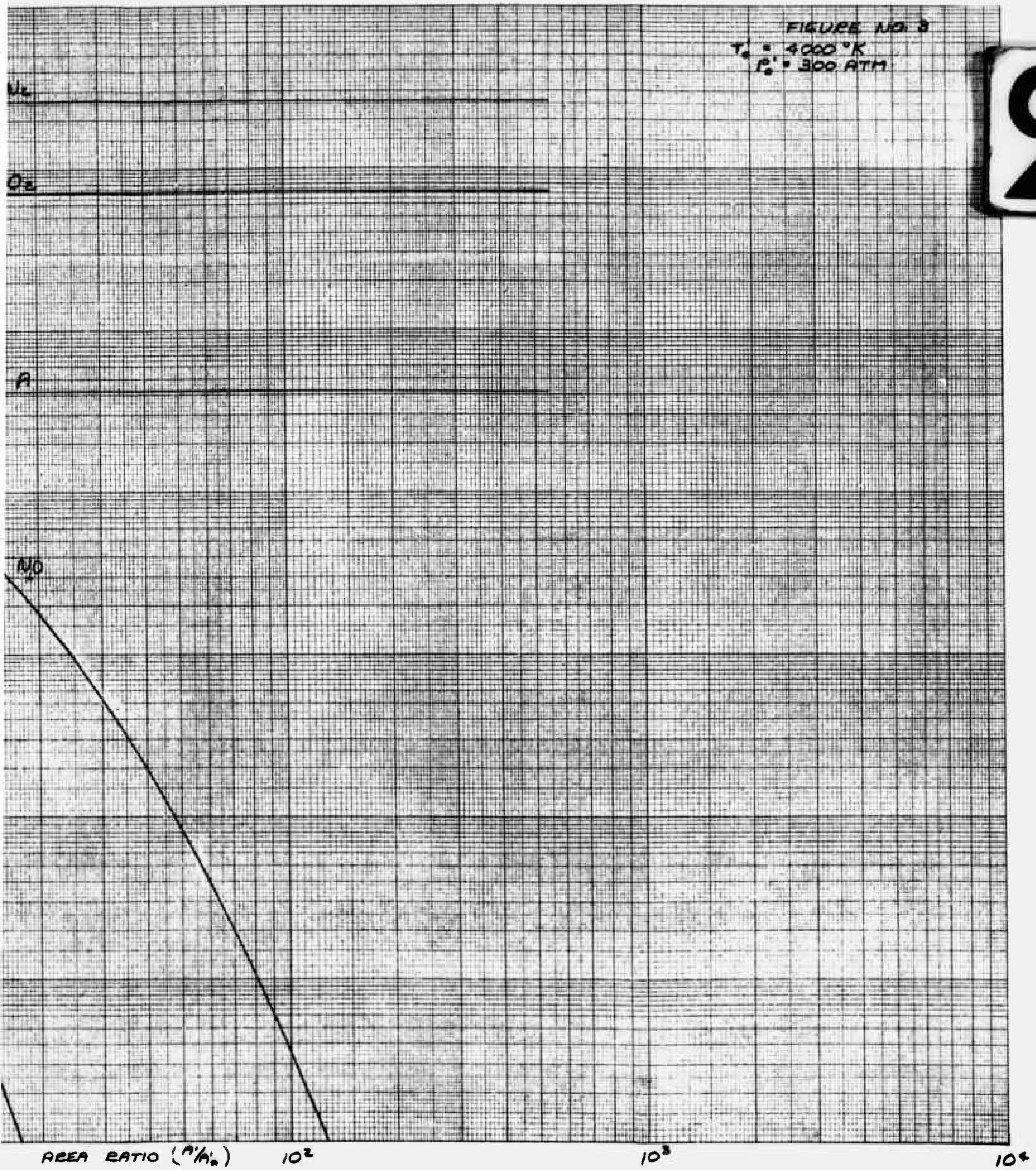
AIR COMPOSITION VS AREA RATIO IN AN ISENTROPIC



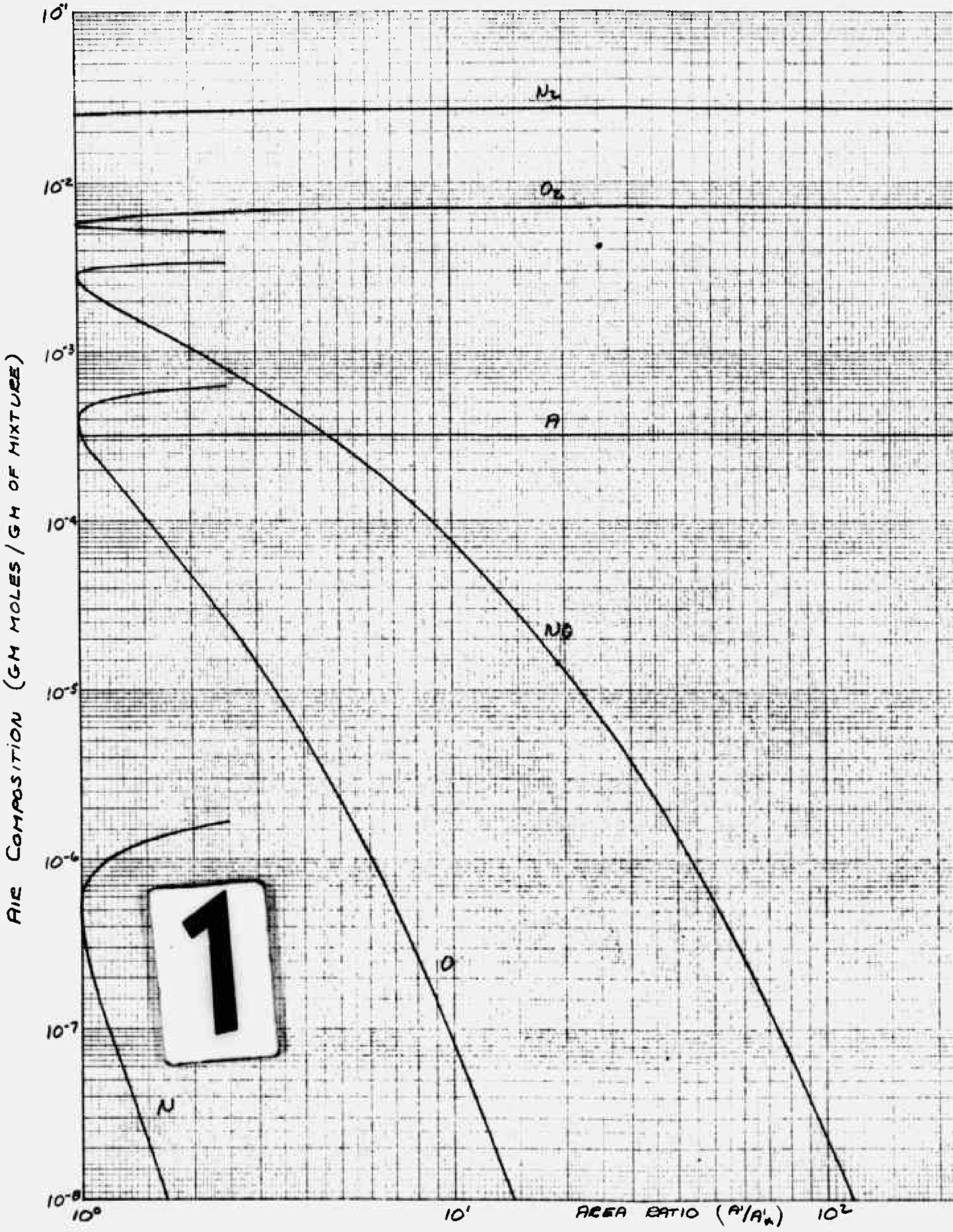
VS AREA RATIO IN AN ISENTROPIC EQUILIBRIUM EXPANSION



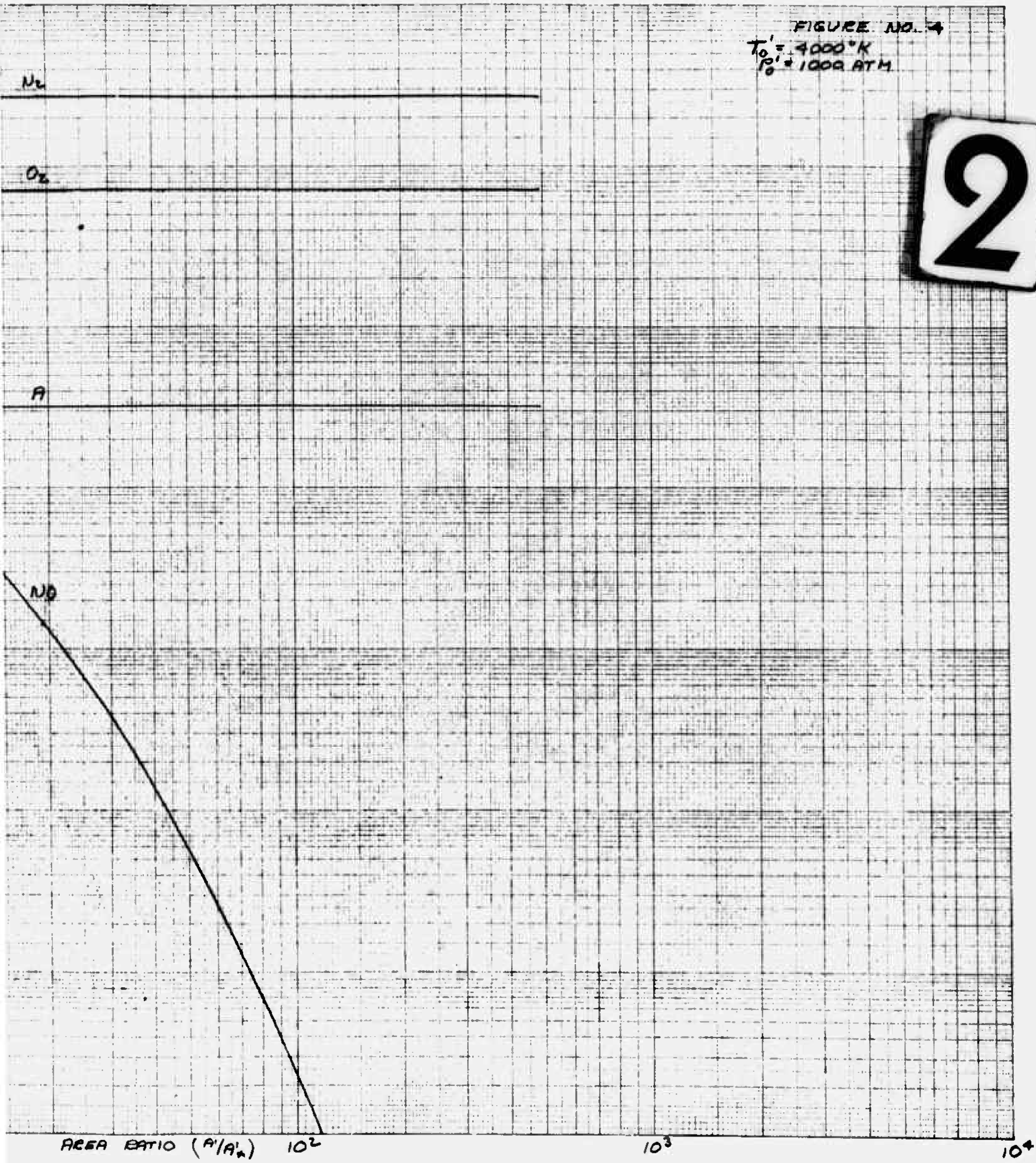
AIR COMPOSITION VS AREA RATIO IN AN



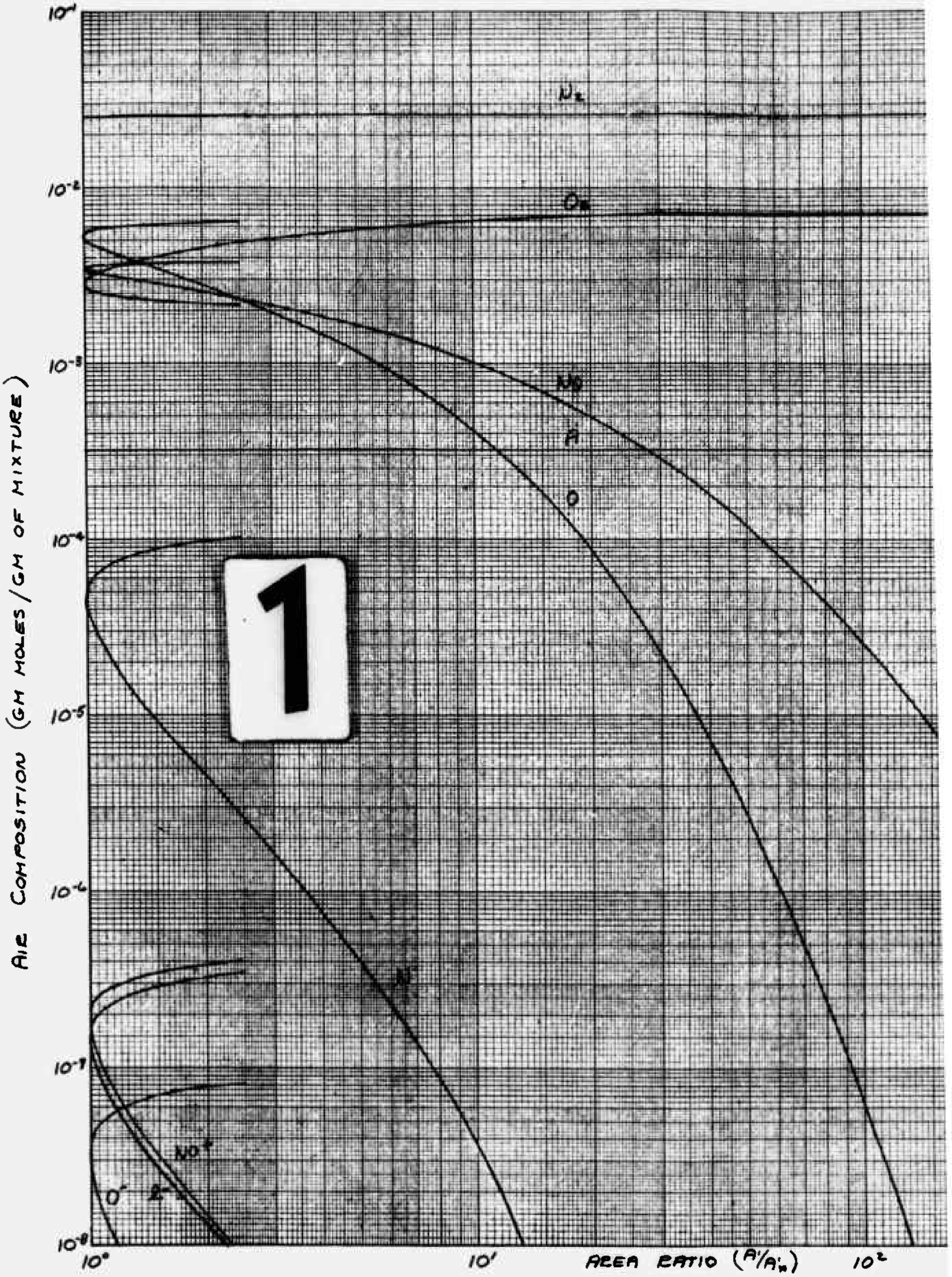
ION VS AREA RATIO IN AN ISENTROPIC EQUILIBRIUM EXPANSION



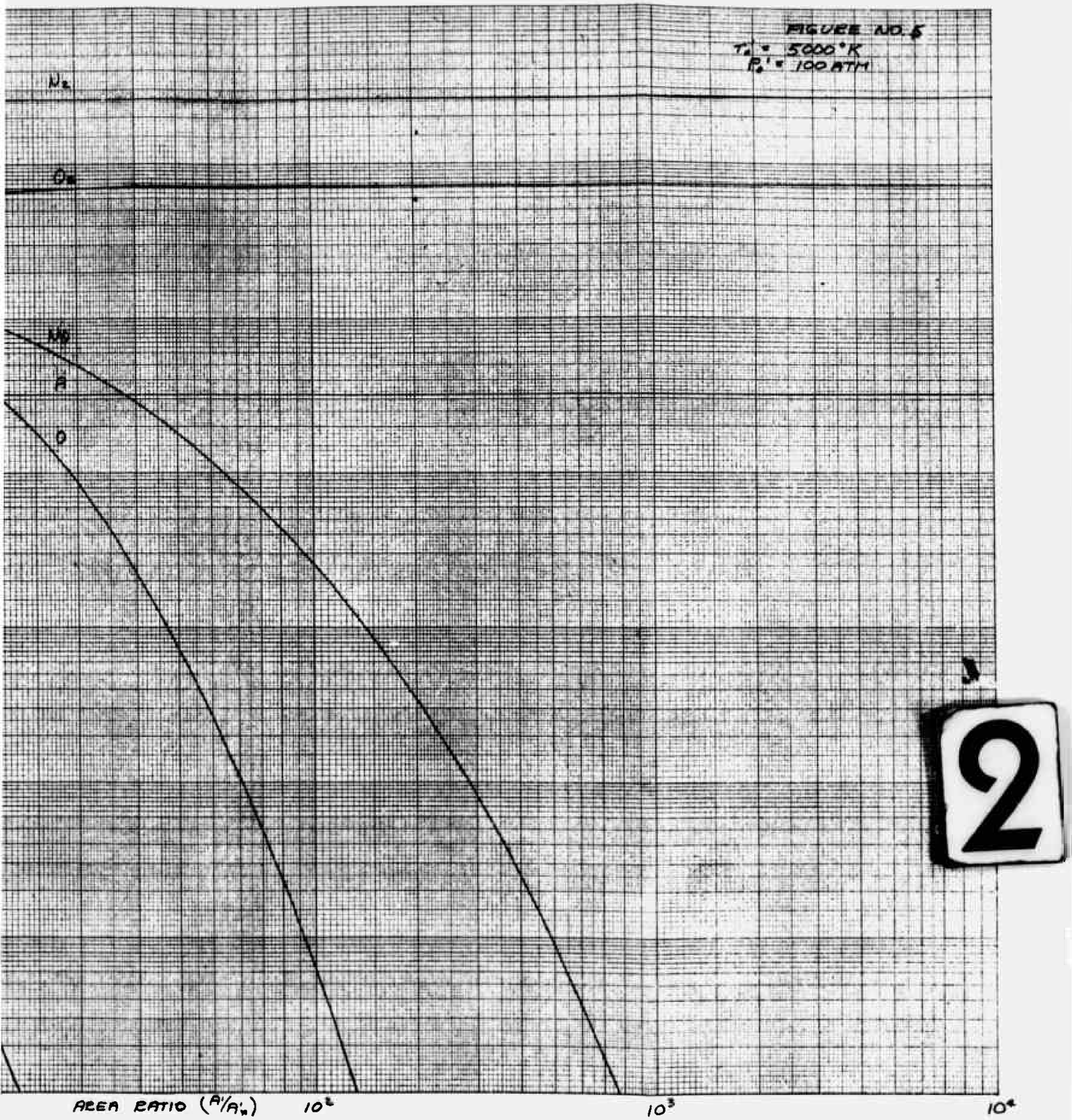
AIR COMPOSITION VS AREA RATIO IN AN J.S



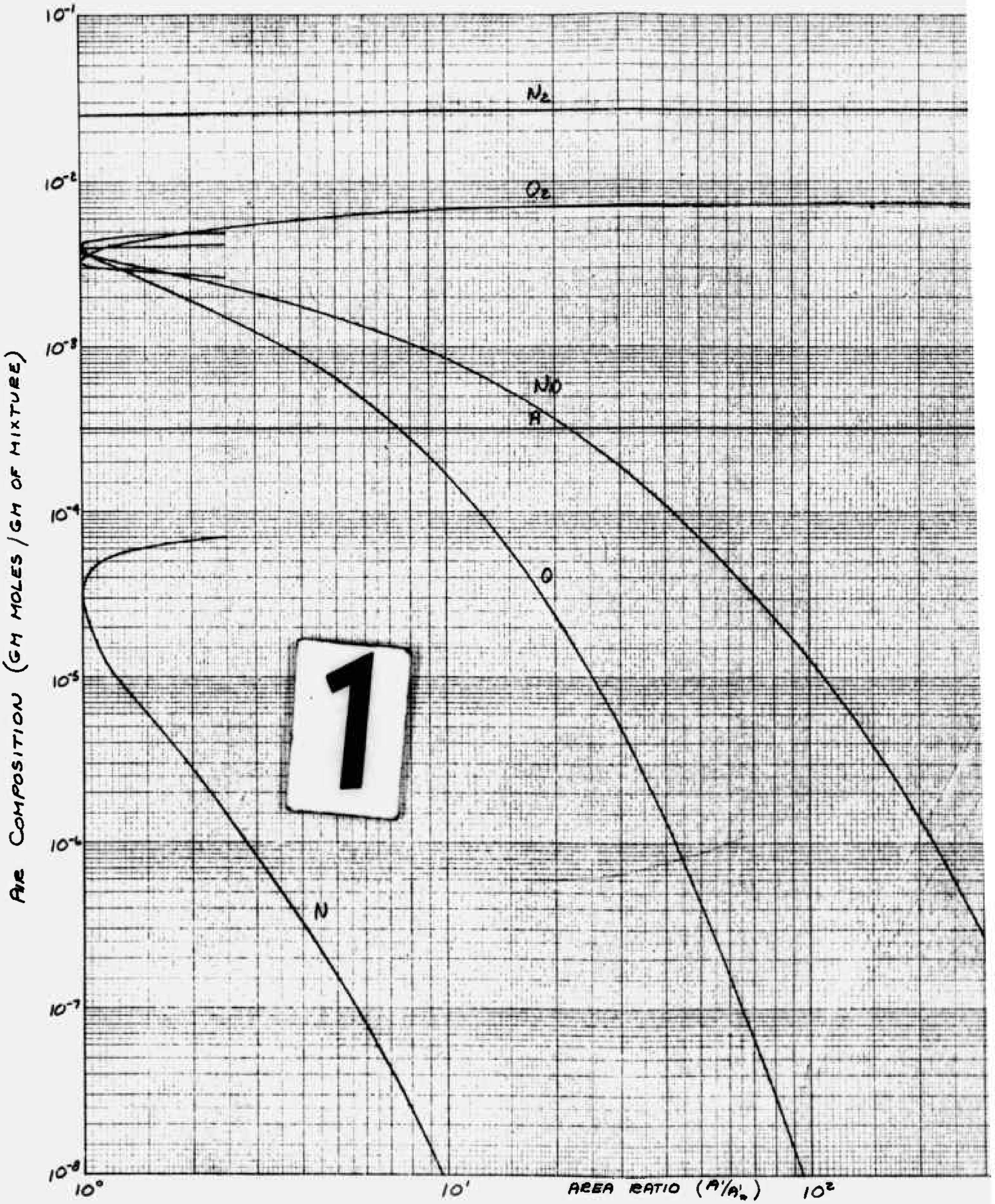
ON VS AREA RATIO IN AN ISENTROPIC EQUILIBRIUM EXPANSION



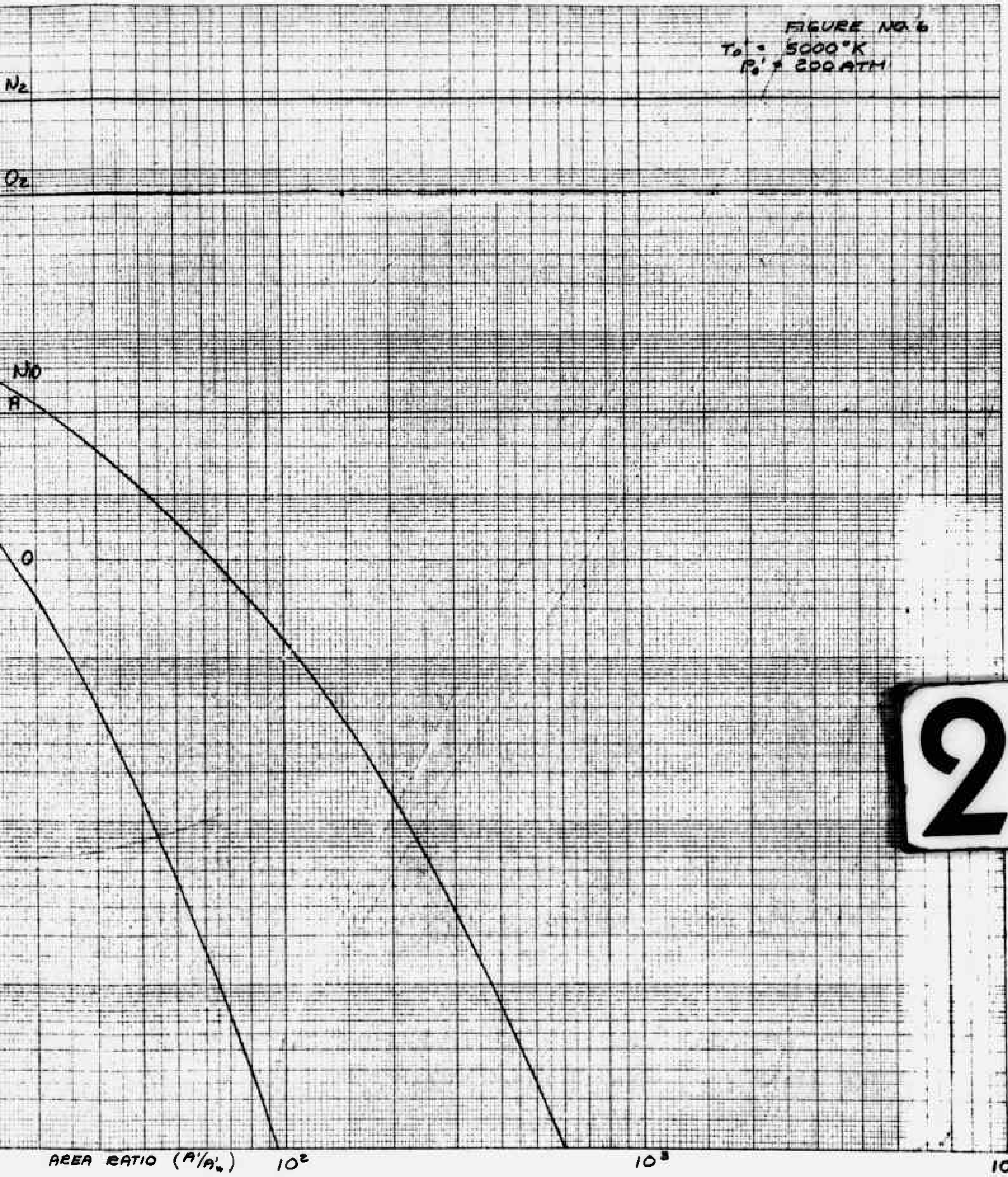
AIR COMPOSITION VS AREA RATIO IN AN ISENTR



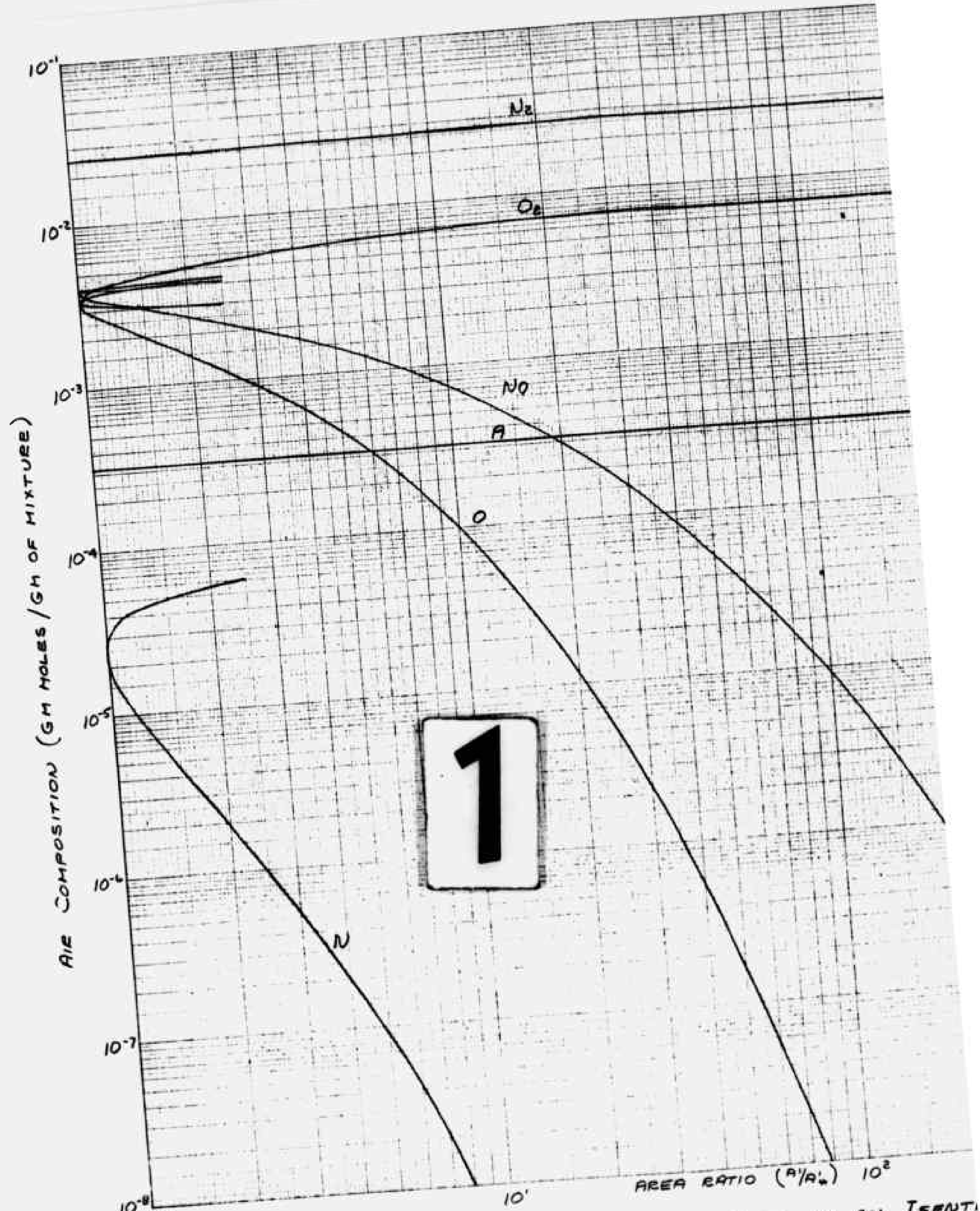
...U VS AREA RATIO IN AN ISENTROPIC EQUILIBRIUM EXPANSION



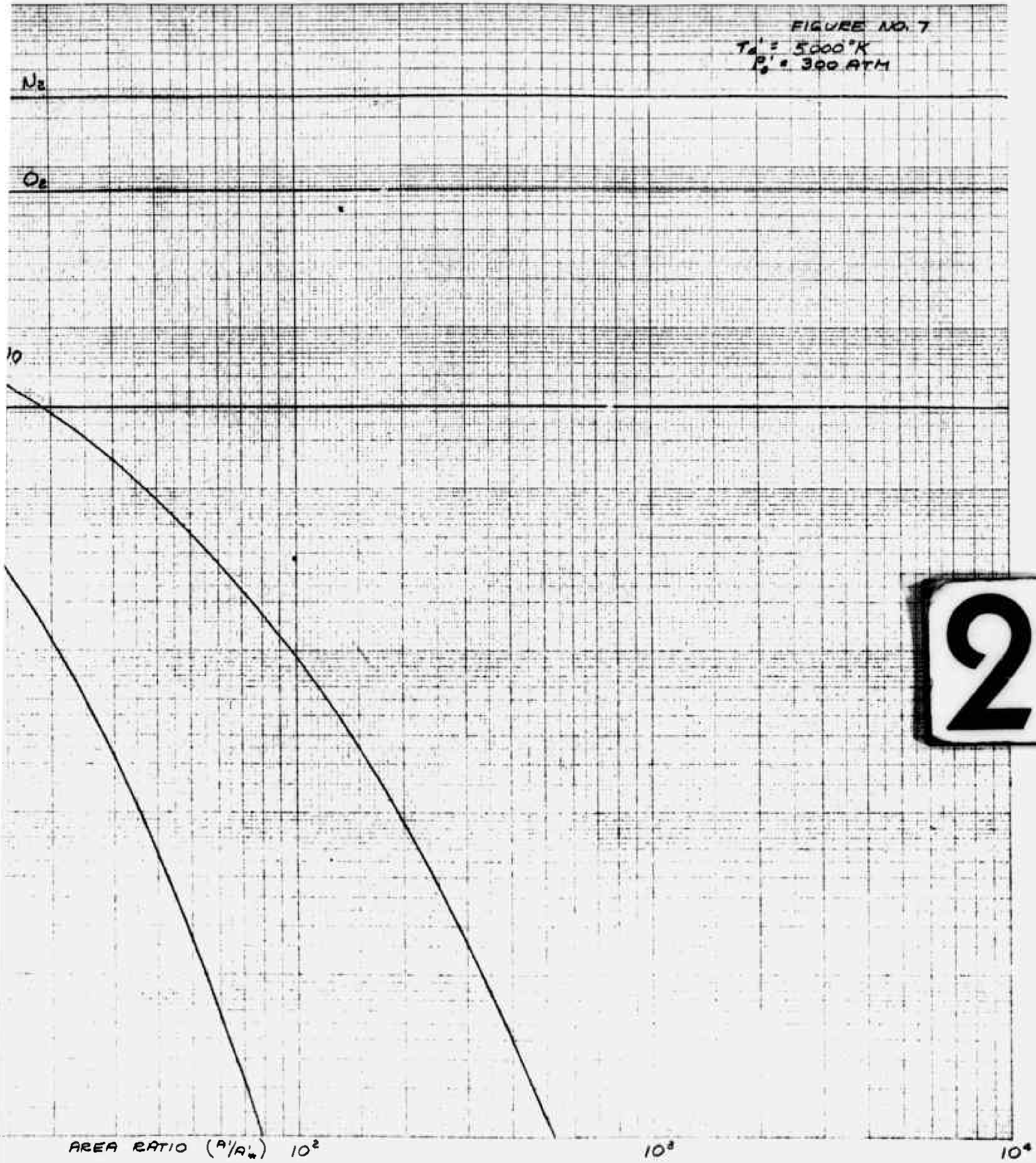
AIR COMPOSITION VS AREA RATIO IN AN ISENTRO



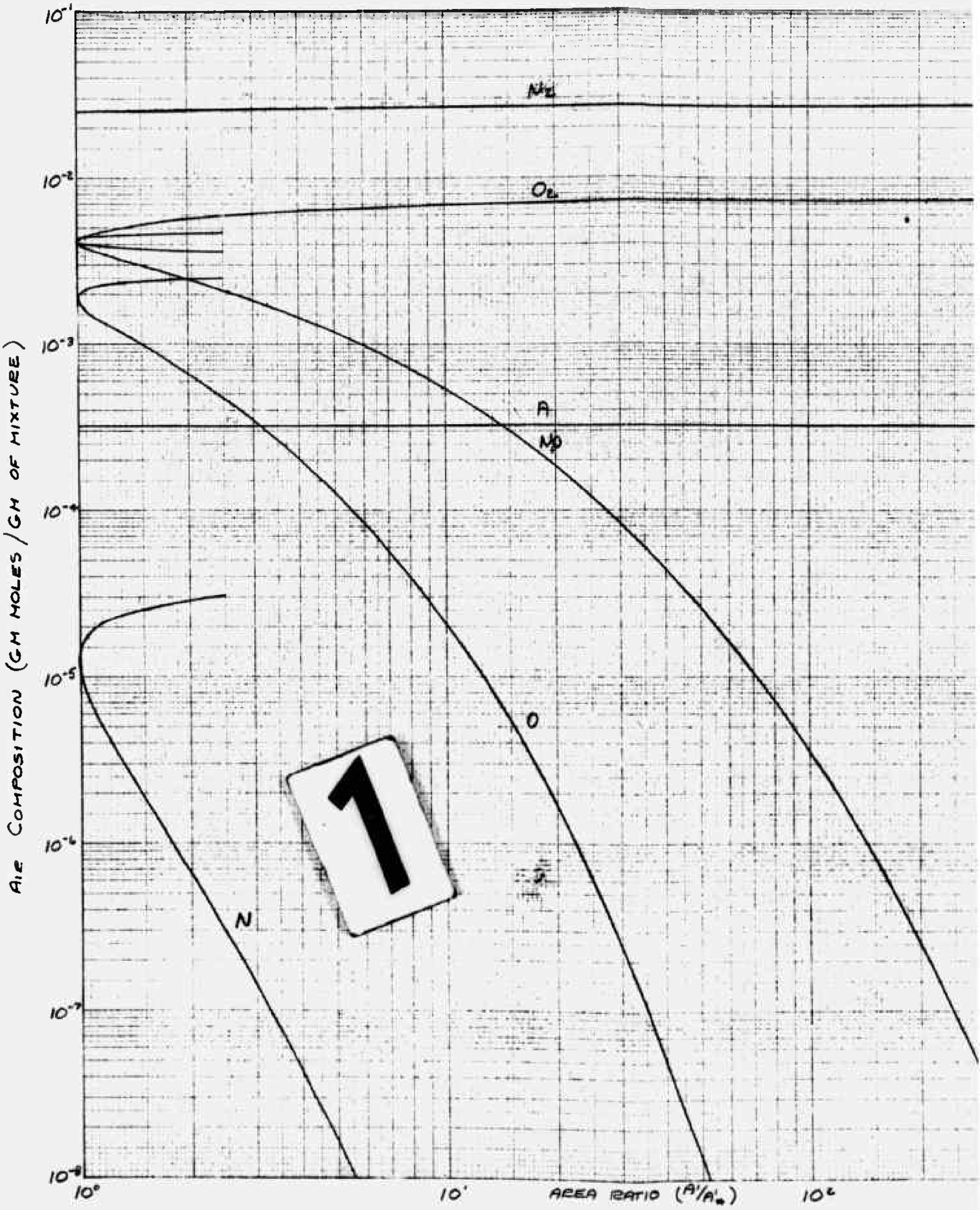
...N VS AREA RATIO IN AN ISENTROPIC EQUILIBRIUM EXPANSION



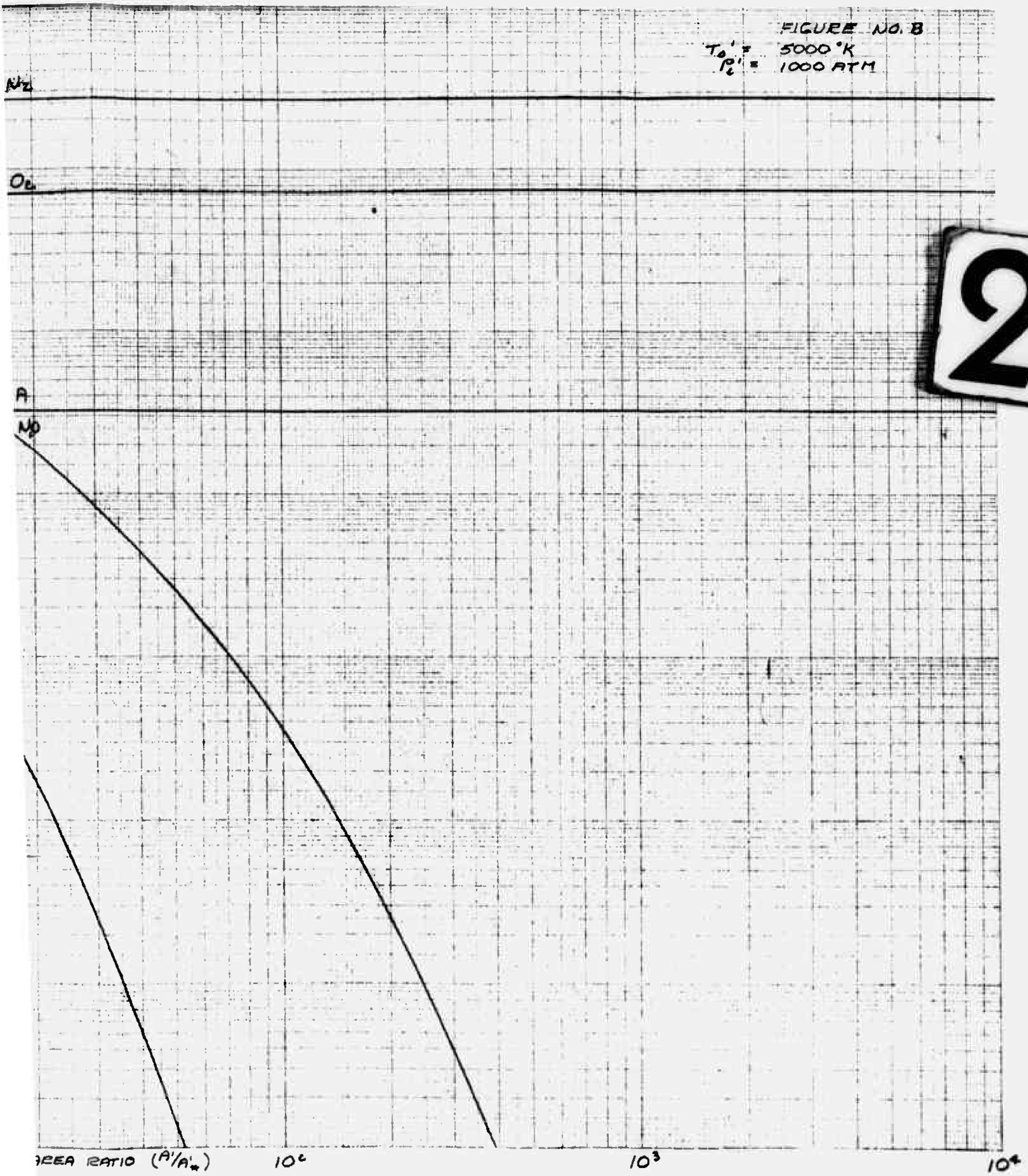
AIR COMPOSITION VS AREA RATIO IN AN ISENT



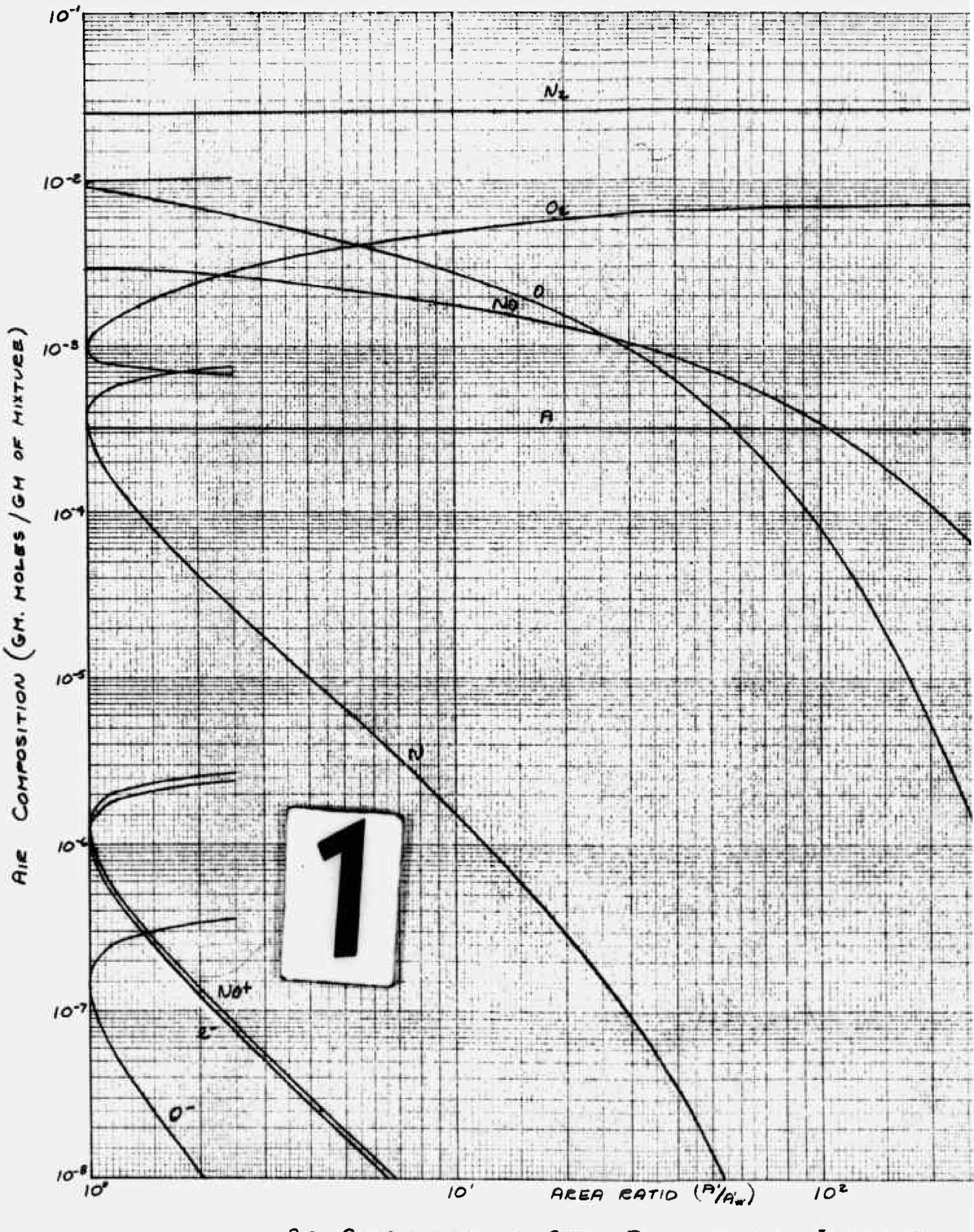
VS AREA RATIO IN AN ISENTROPIC EQUILIBRIUM EXPANSION



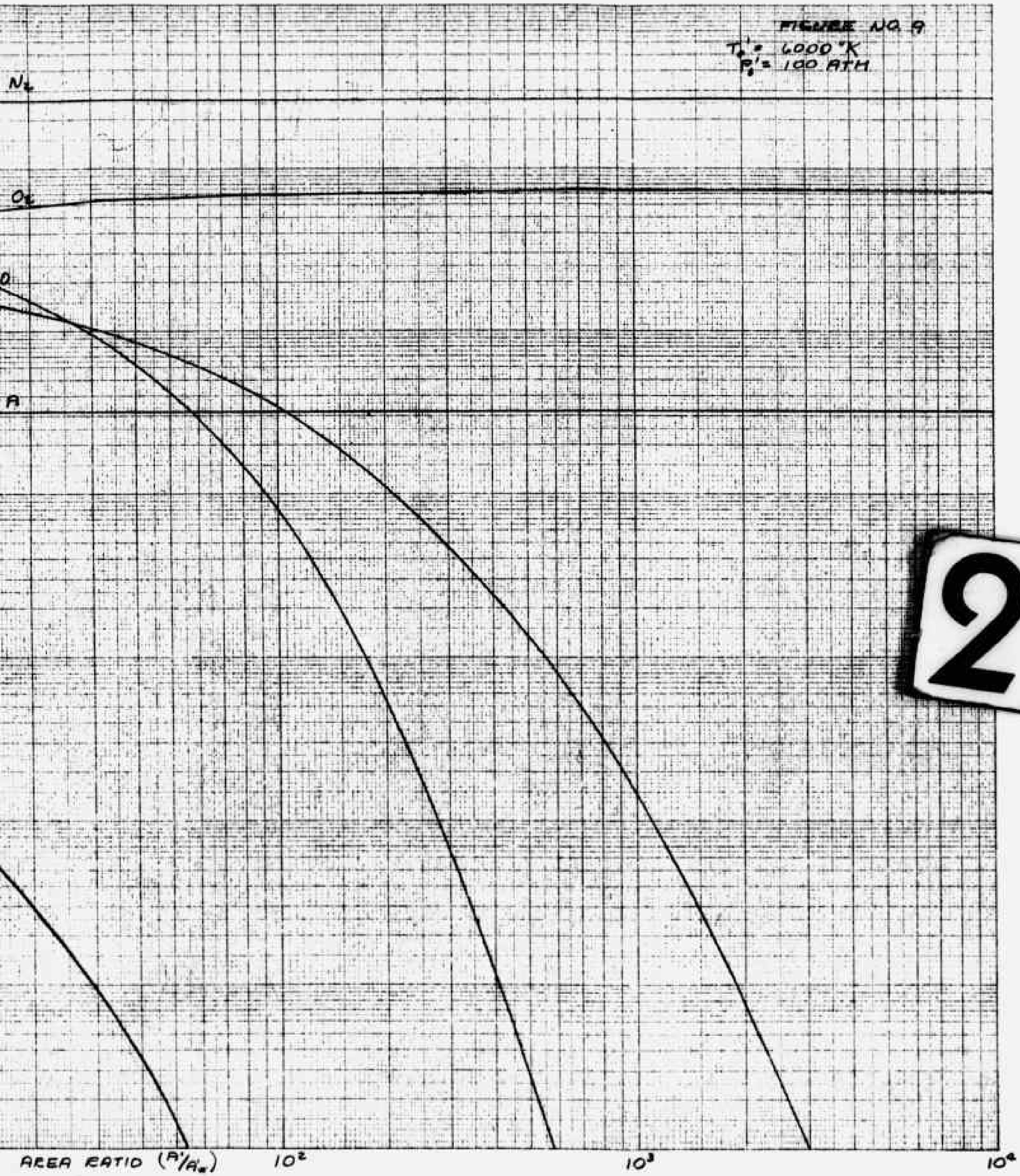
AIR COMPOSITION VS AREA RATIO IN AN ISENTROPIC



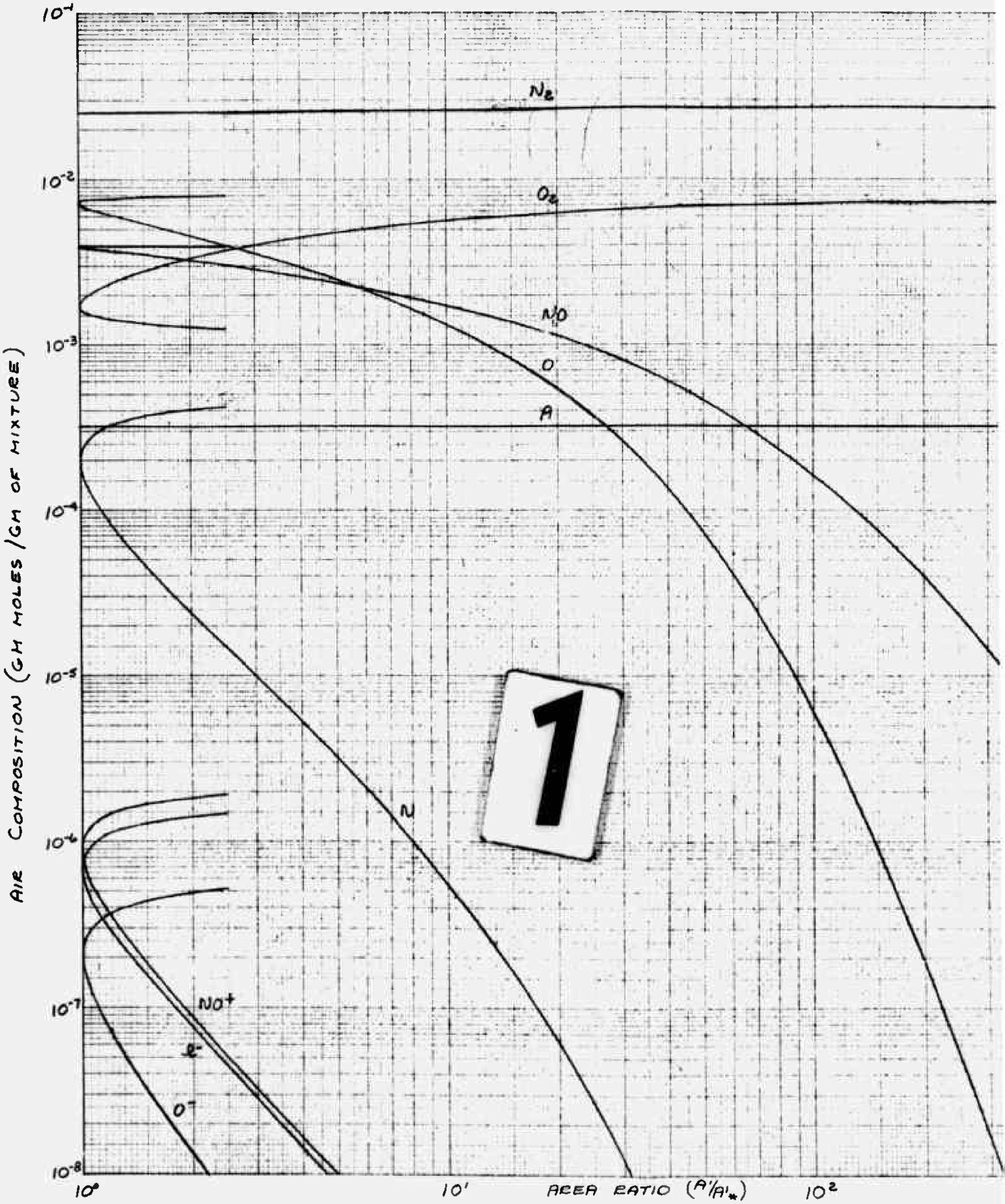
AREA RATIO IN AN ISENTROPIC EQUILIBRIUM EXPANSION



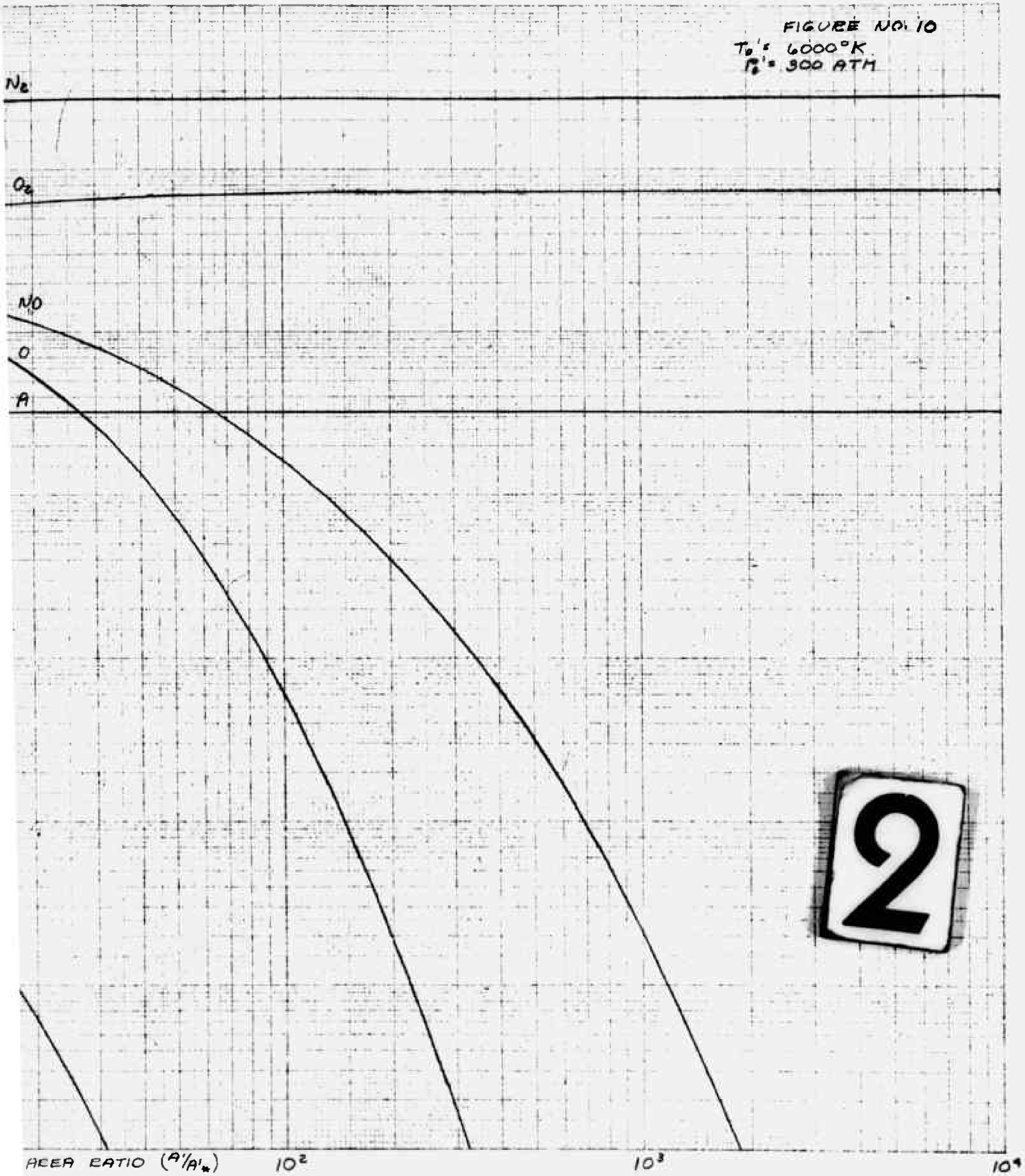
AIR COMPOSITION VS AREA RATIO IN AN ISENTROPIC



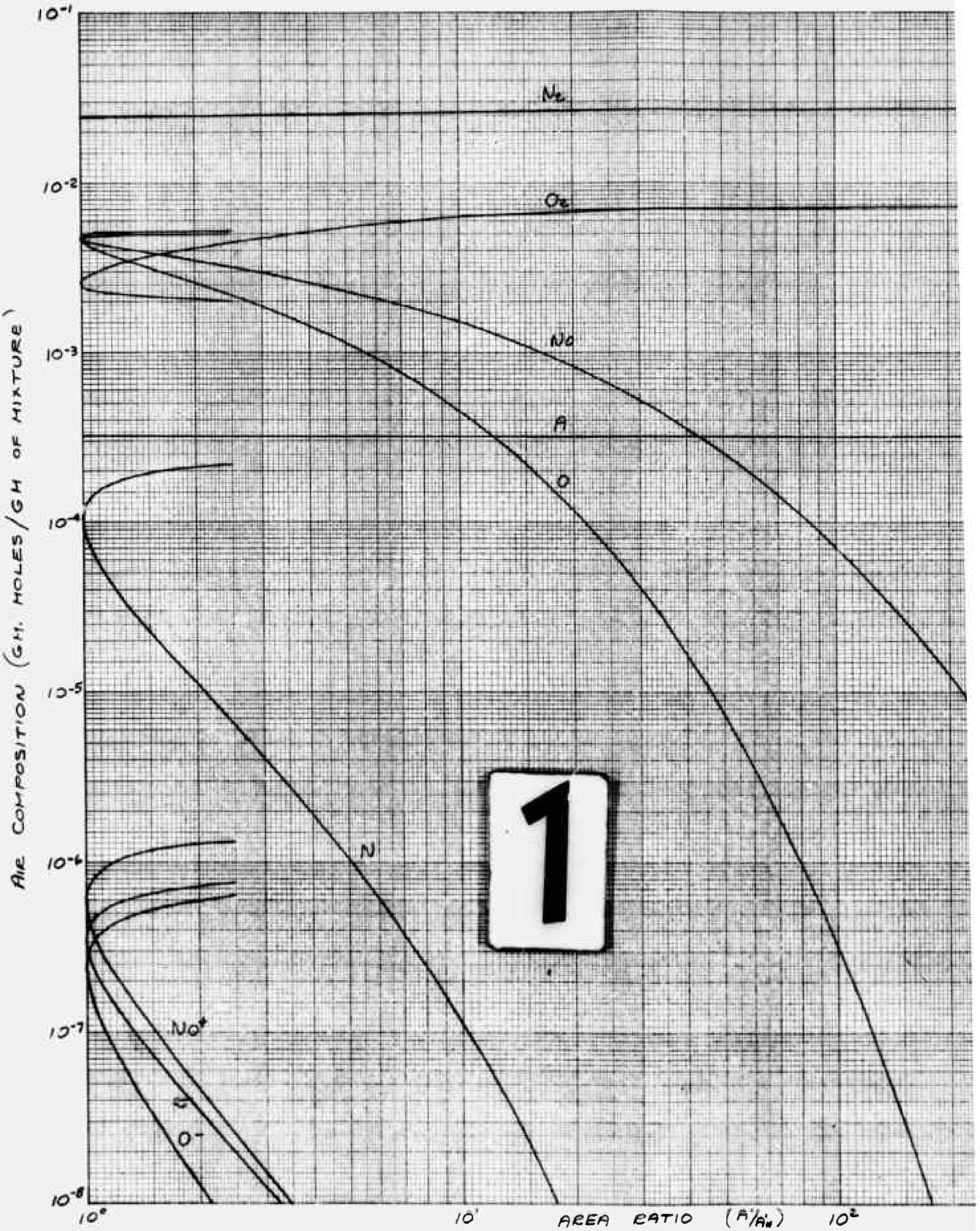
AREA RATIO IN AN ISENTROPIC EQUILIBRIUM EXPANSION



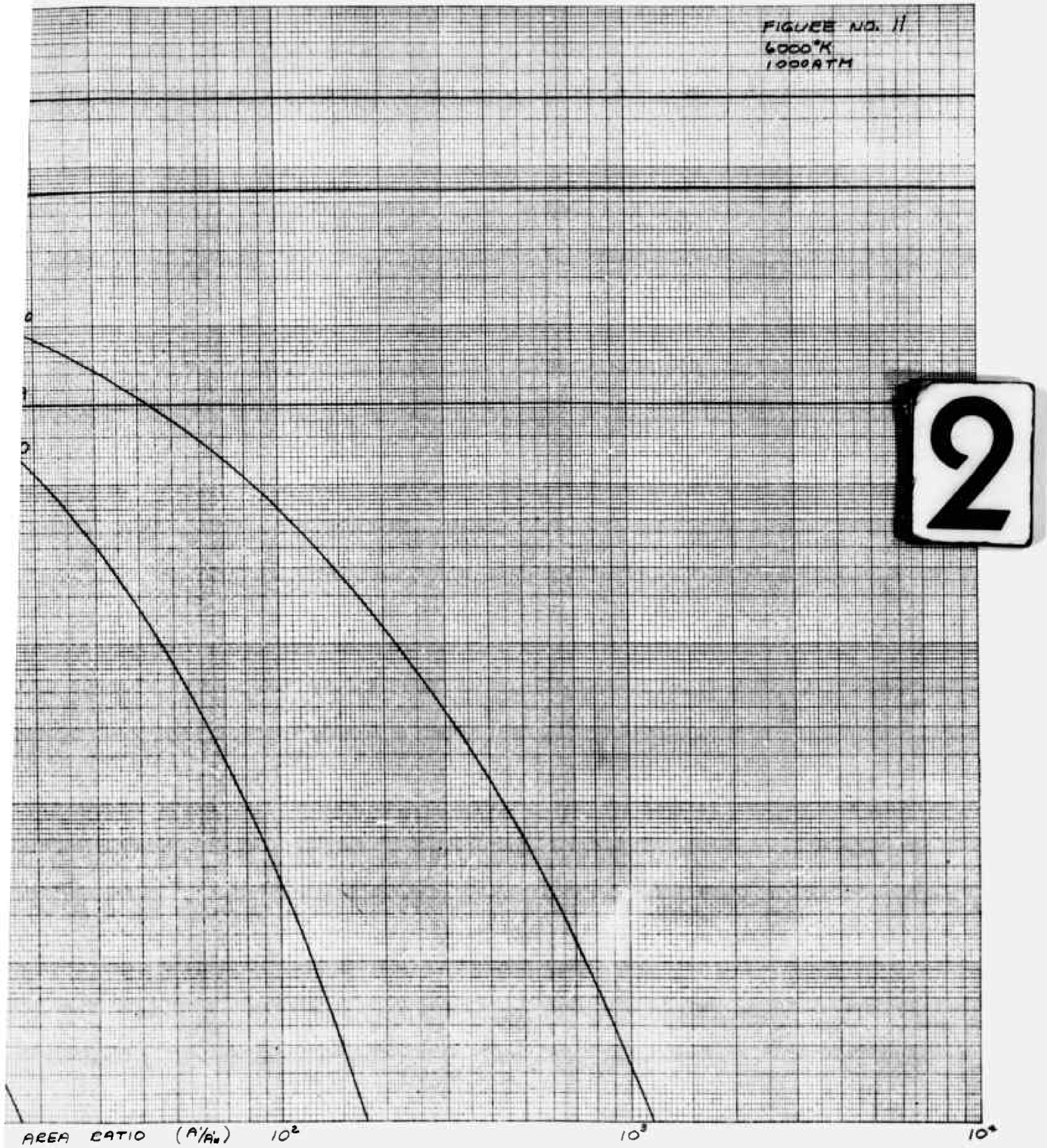
AIR COMPOSITION VS AREA RATIO IN AN ISENTROPIC E



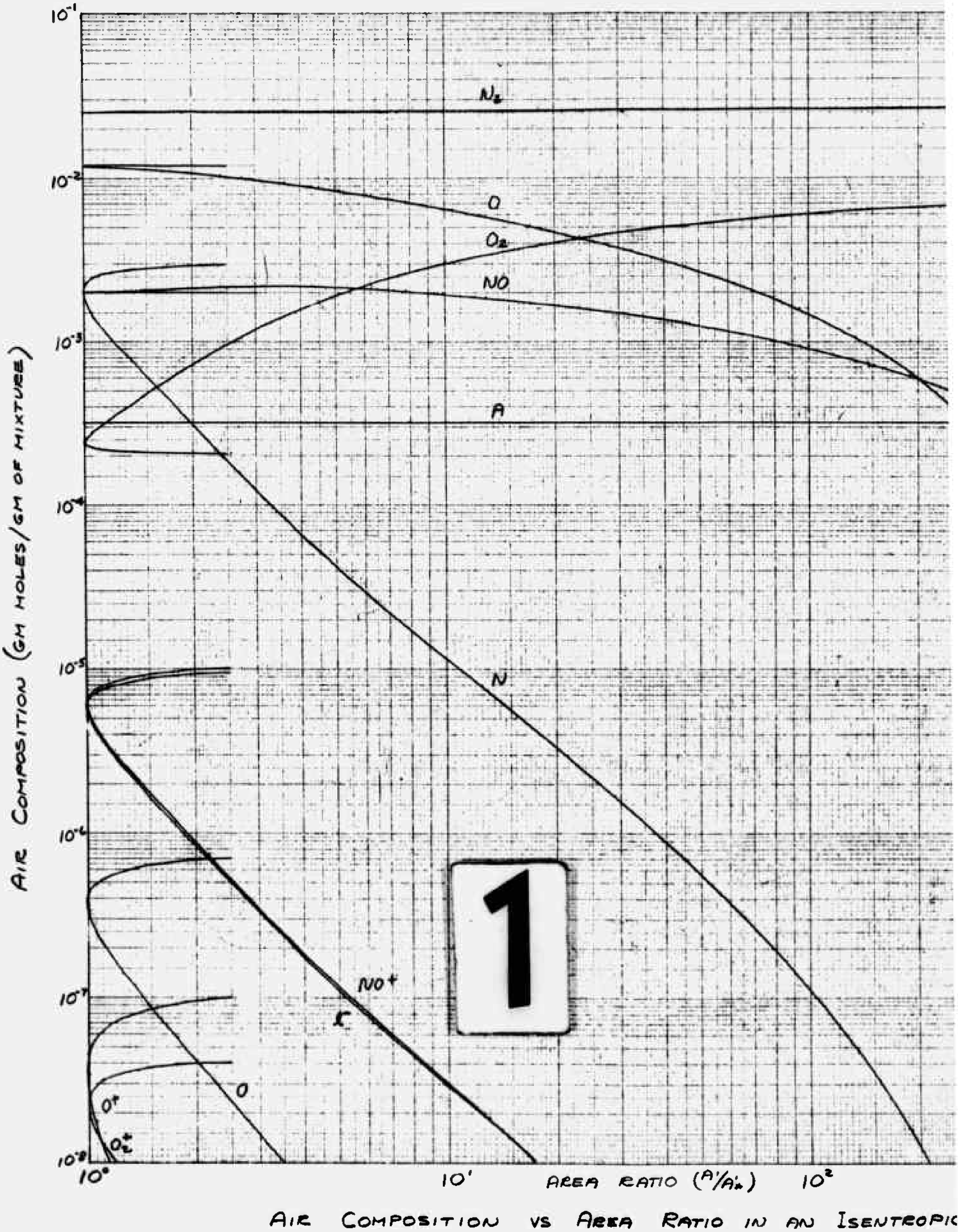
AREA RATIO IN AN ISENTROPIC EQUILIBRIUM EXPANSION



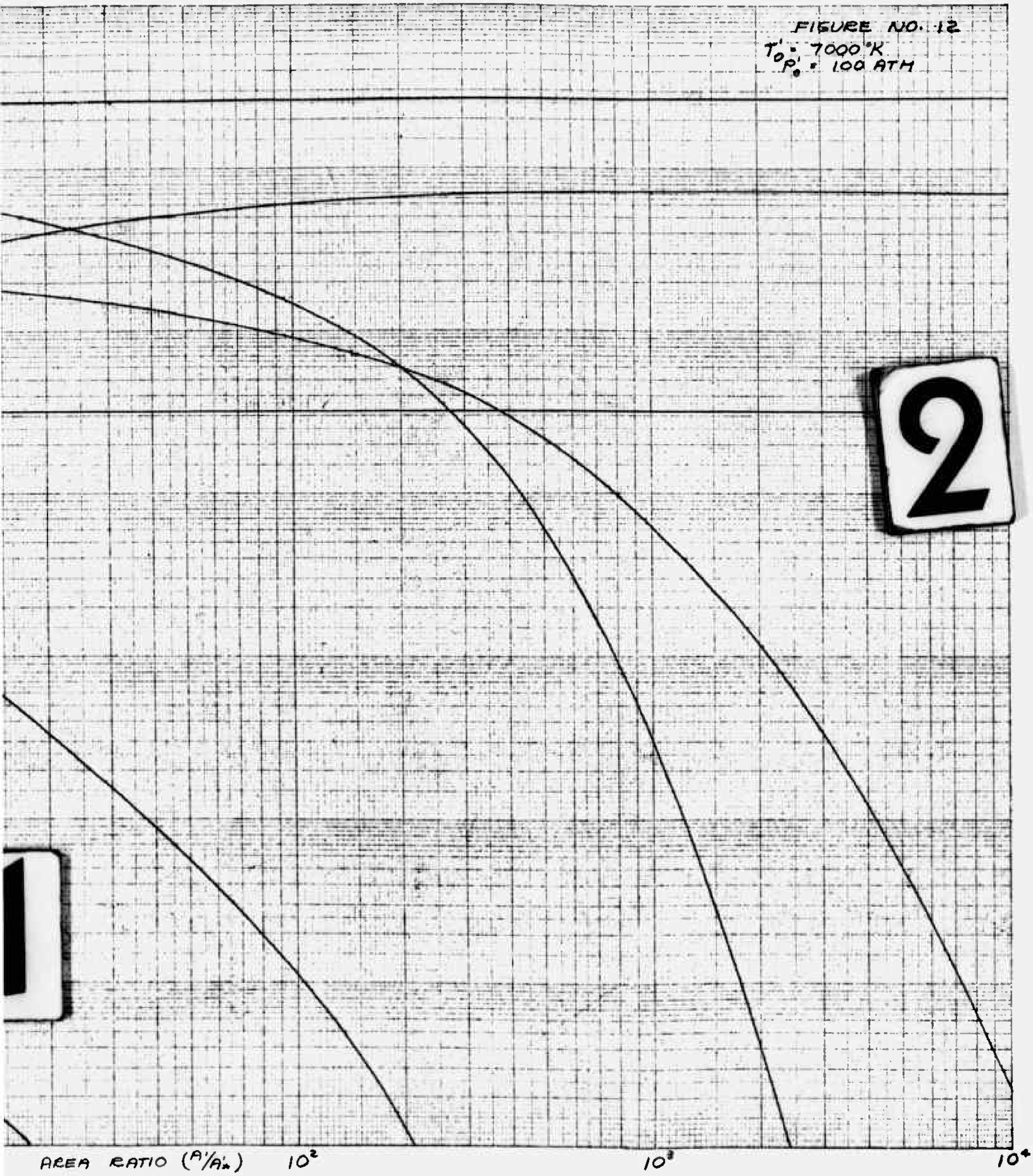
AIR COMPOSITION VS AREA RATIO IN AN ISENTROPIC EQUIL



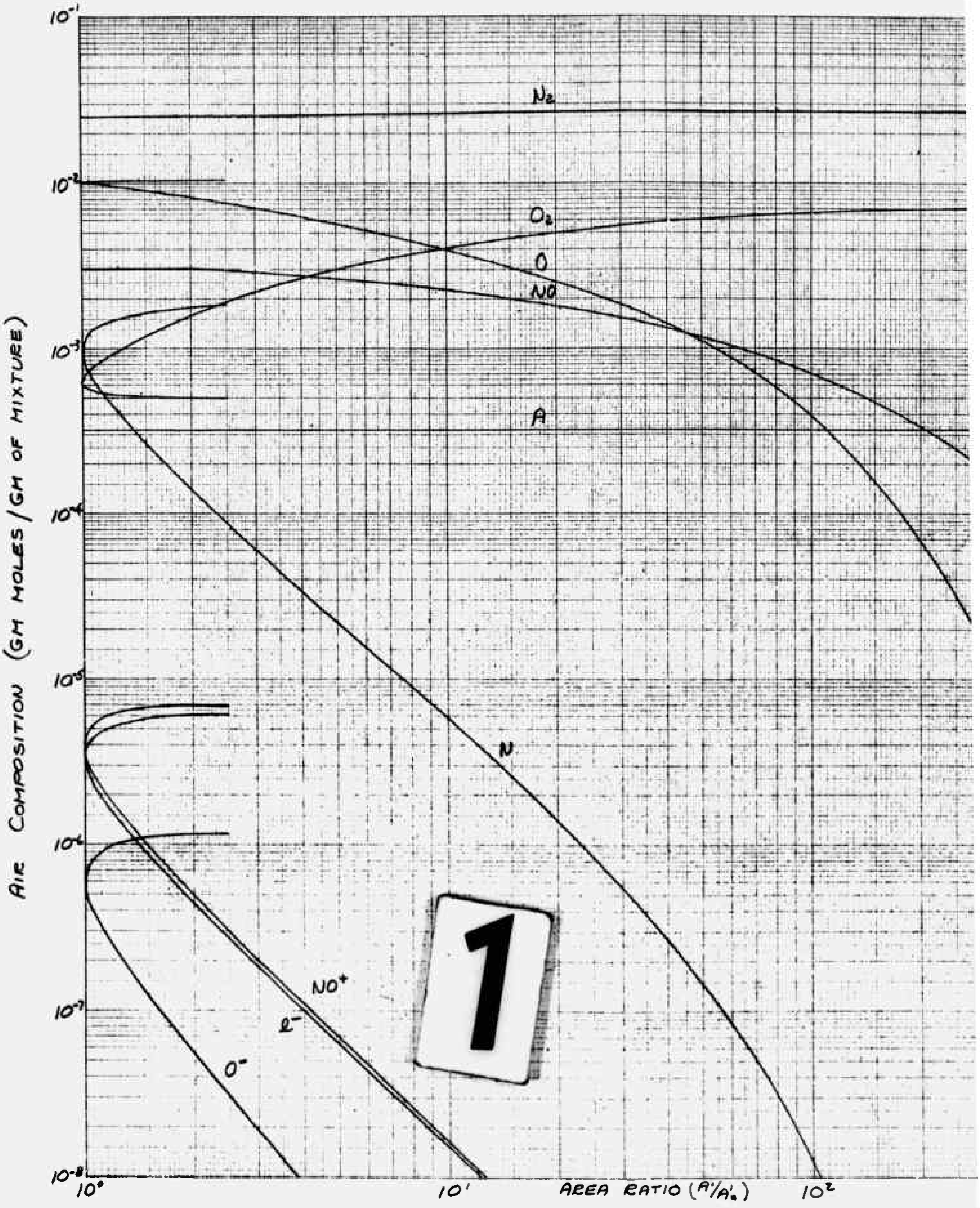
A RATIO IN AN ISENTROPIC EQUILIBRIUM EXPANSION



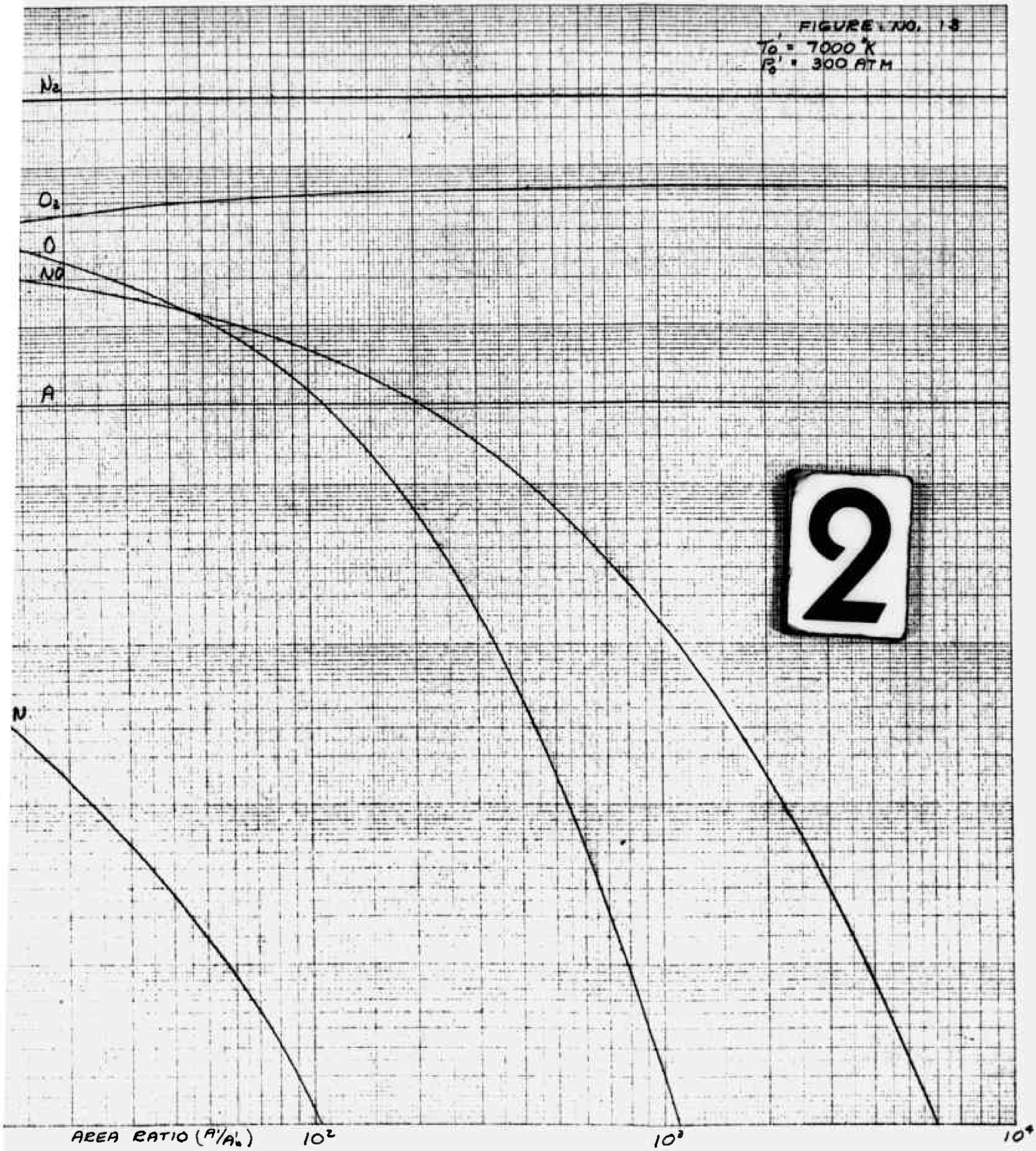
AIR COMPOSITION VS AREA RATIO IN AN ISENTROPIC



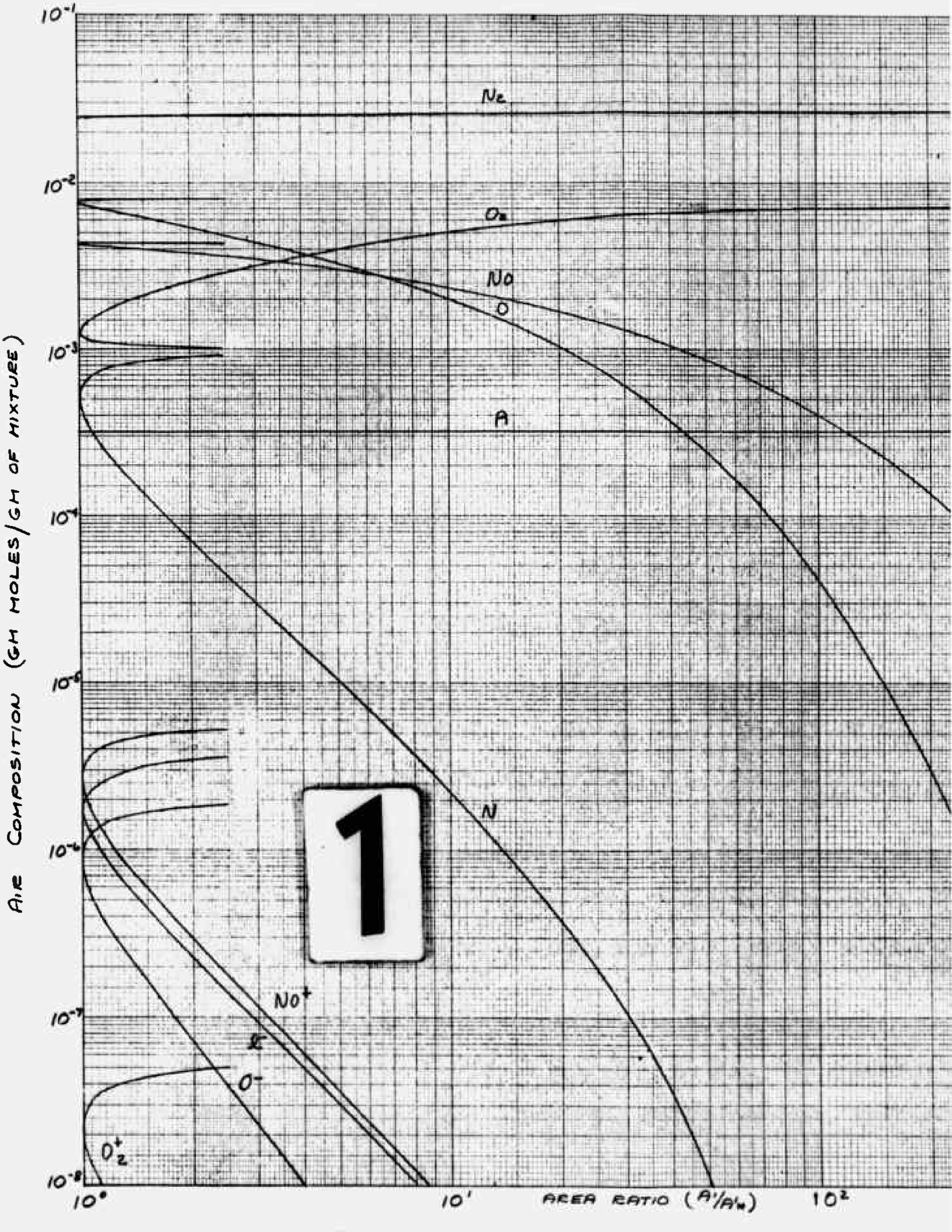
VS AREA RATIO IN AN ISENTROPIC EQUILIBRIUM EXPANSION



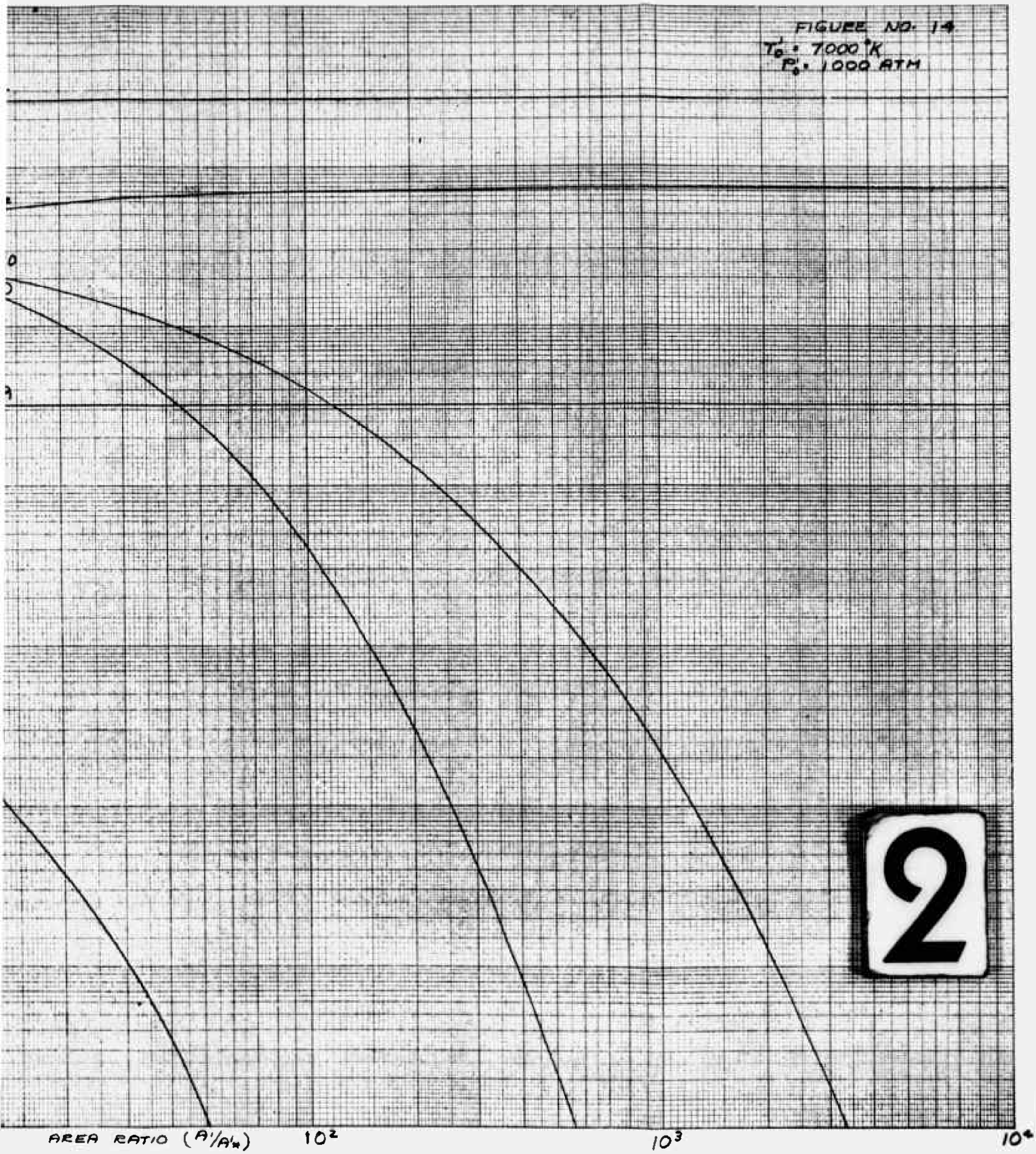
AIR COMPOSITION VS AREA RATIO IN AN ISENTROP



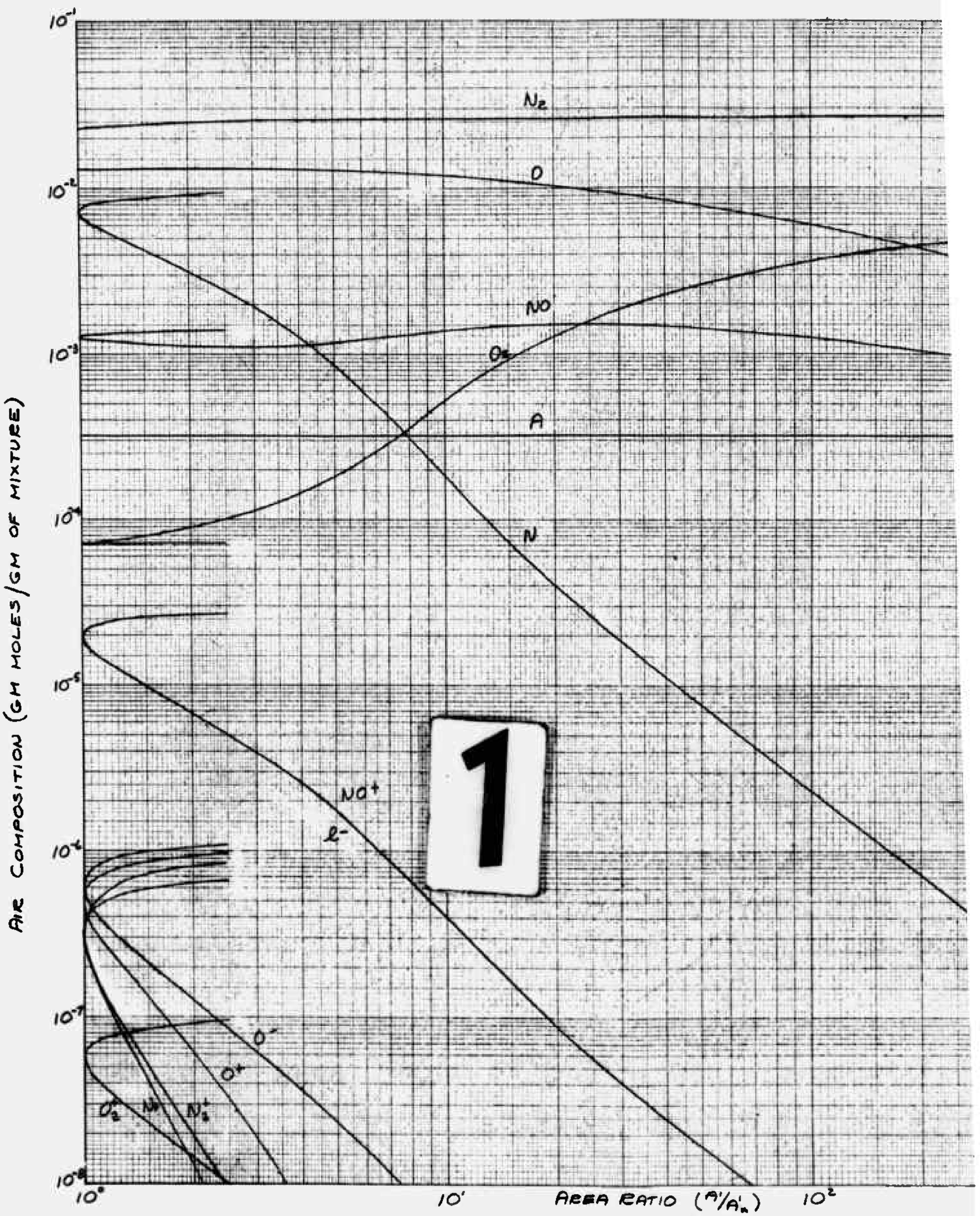
ON VS AREA RATIO IN AN ISENTROPIC EQUILIBRIUM EXPANSION



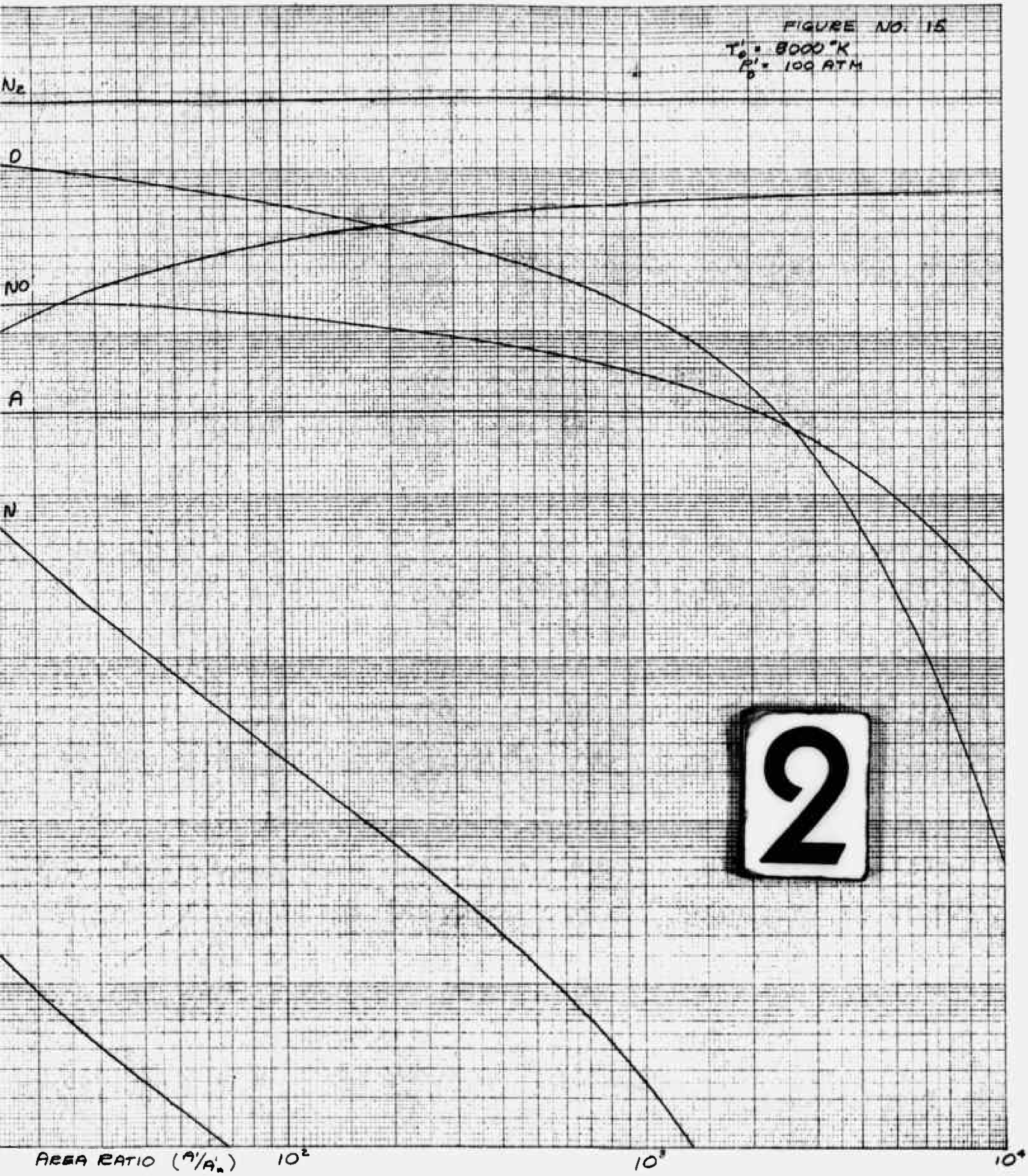
Air Composition vs Area Ratio in an Isentropic



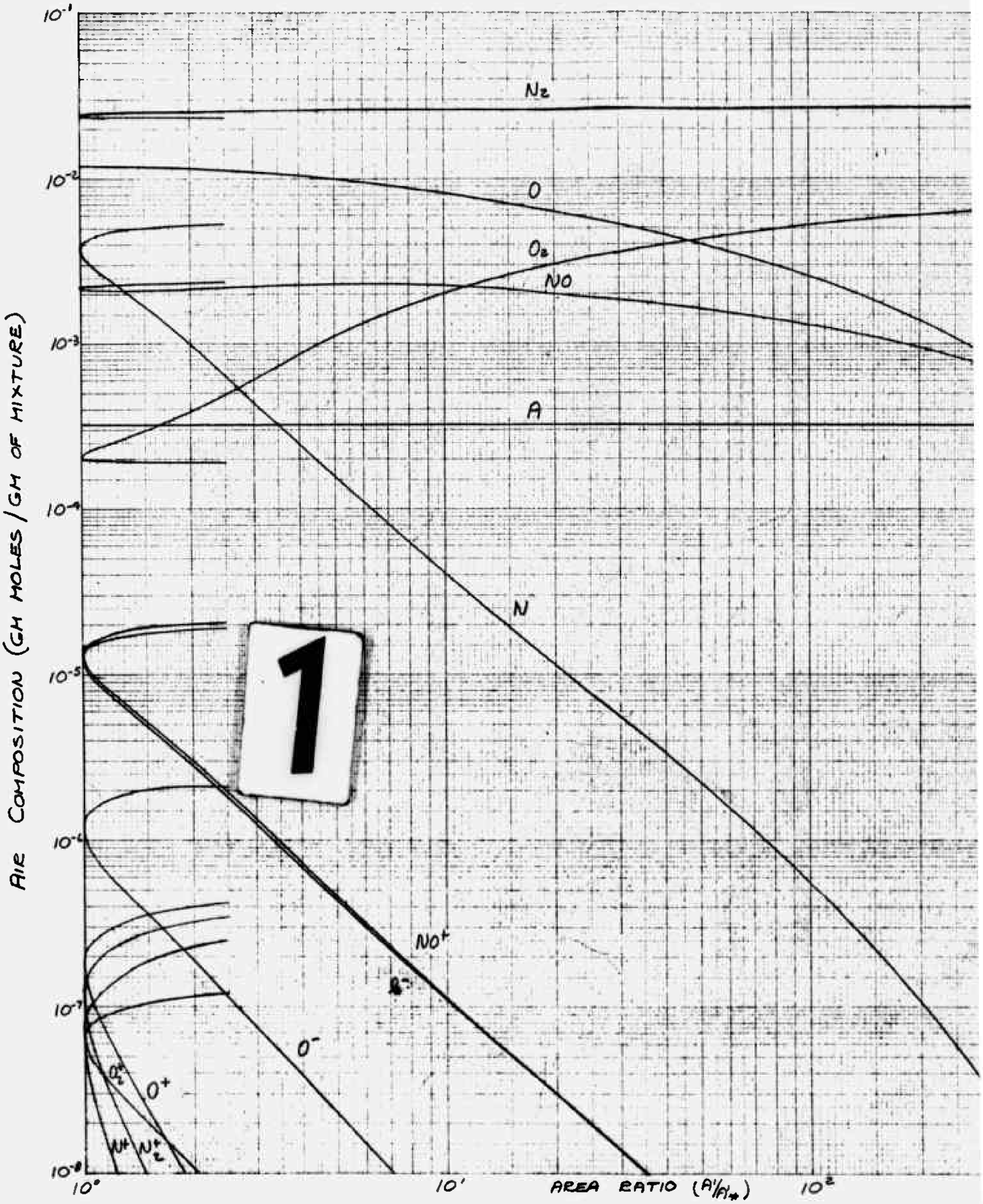
VS AREA RATIO IN AN ISENTROPIC EQUILIBRIUM EXPANSION



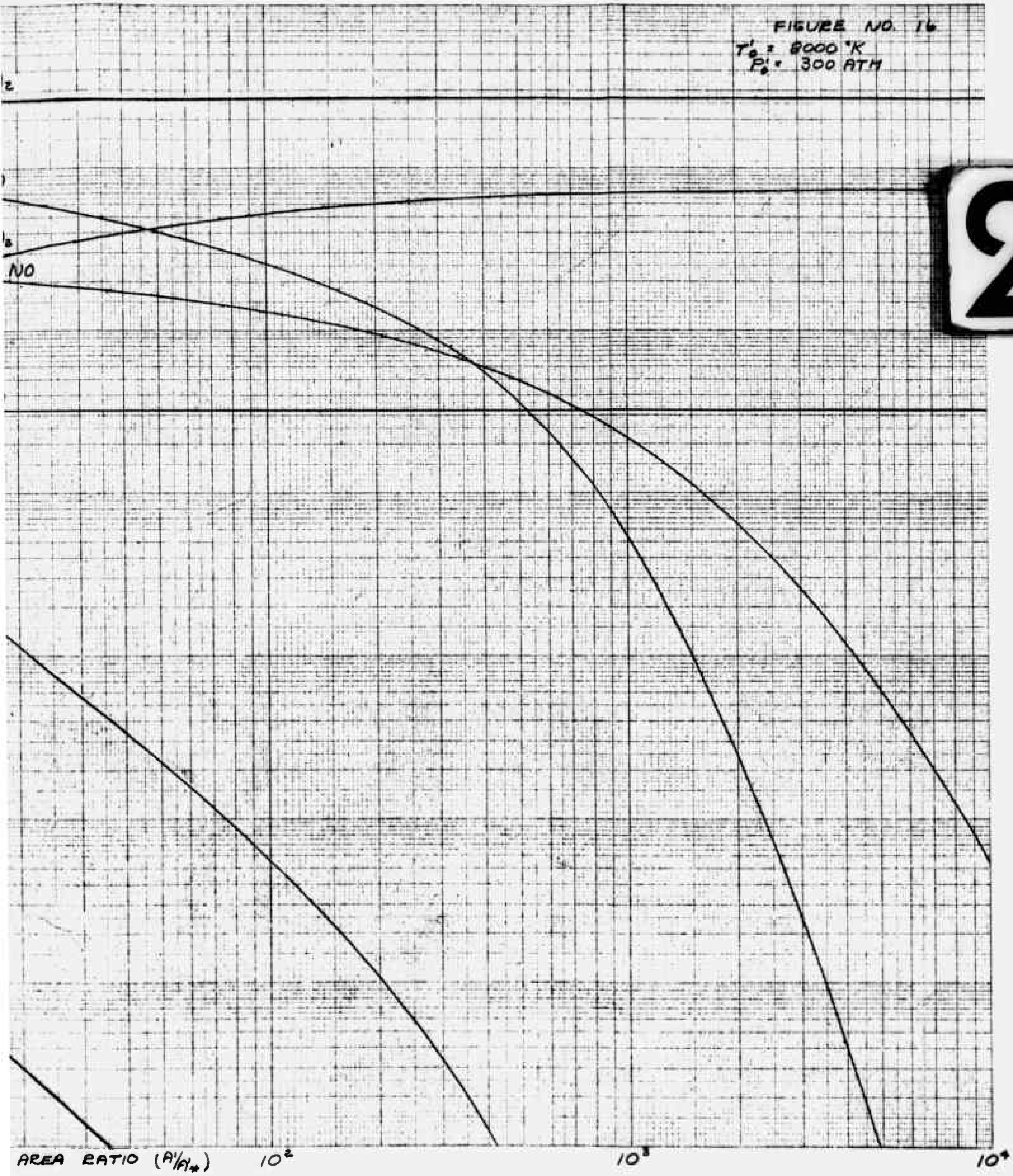
AIR COMPOSITION VS AREA RATIO IN AN ISENTROPIC E



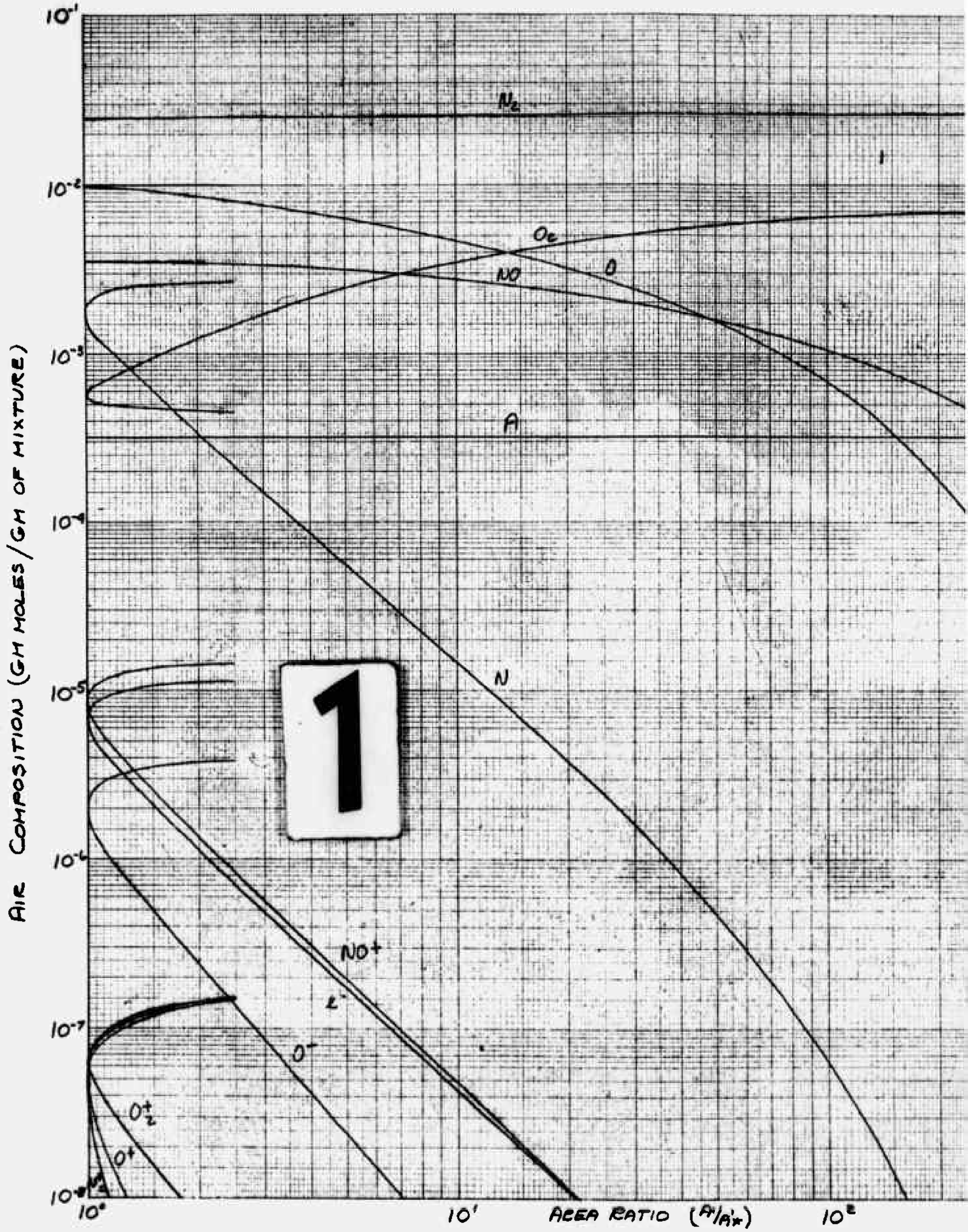
VS AREA RATIO IN AN ISENTROPIC EQUILIBRIUM EXPANSION



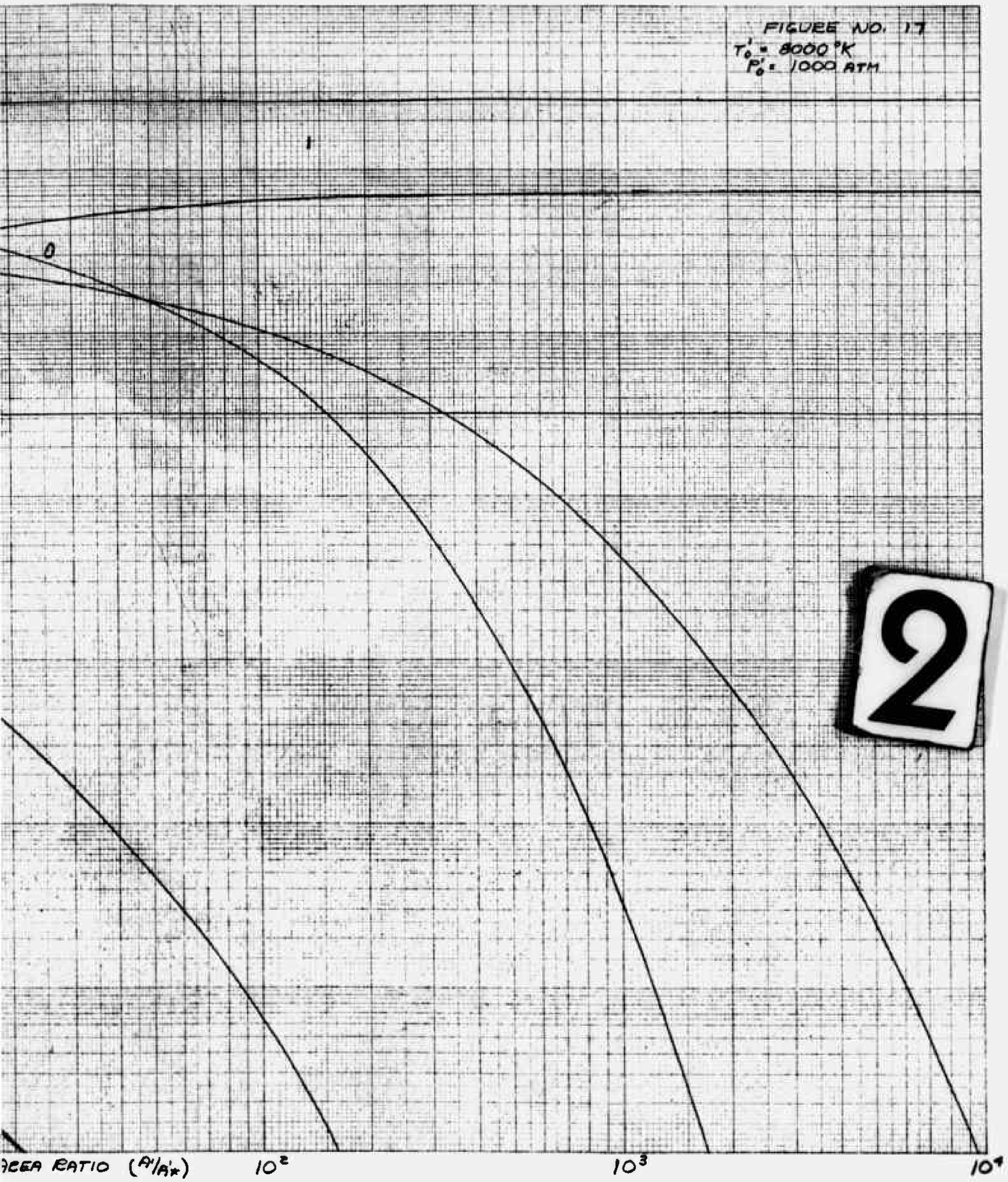
AIR COMPOSITION VS AREA RATIO IN AN ISENTROP



VS AREA RATIO IN AN ISENTROPIC EQUILIBRIUM EXPANSION



AIR COMPOSITION VS AREA RATIO IN AN ISENTROPIC



AREA RATIO IN AN ISENTROPIC EQUILIBRIUM EXPANSION

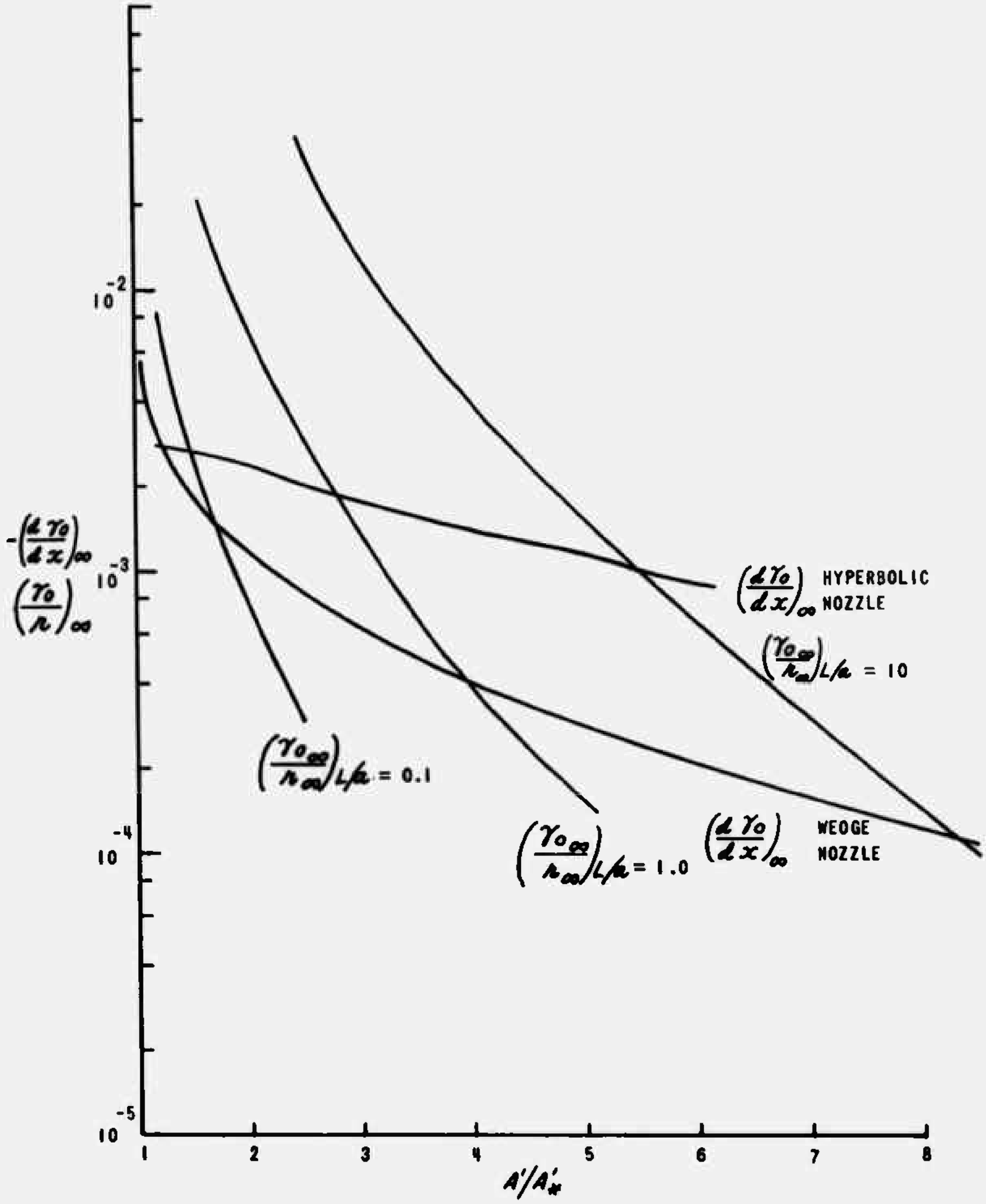


Figure 18 SAMPLE SOLUTION OF EQUATION (36) $T_0' = 5000°$ K, $P_0' = 100$ ATM.

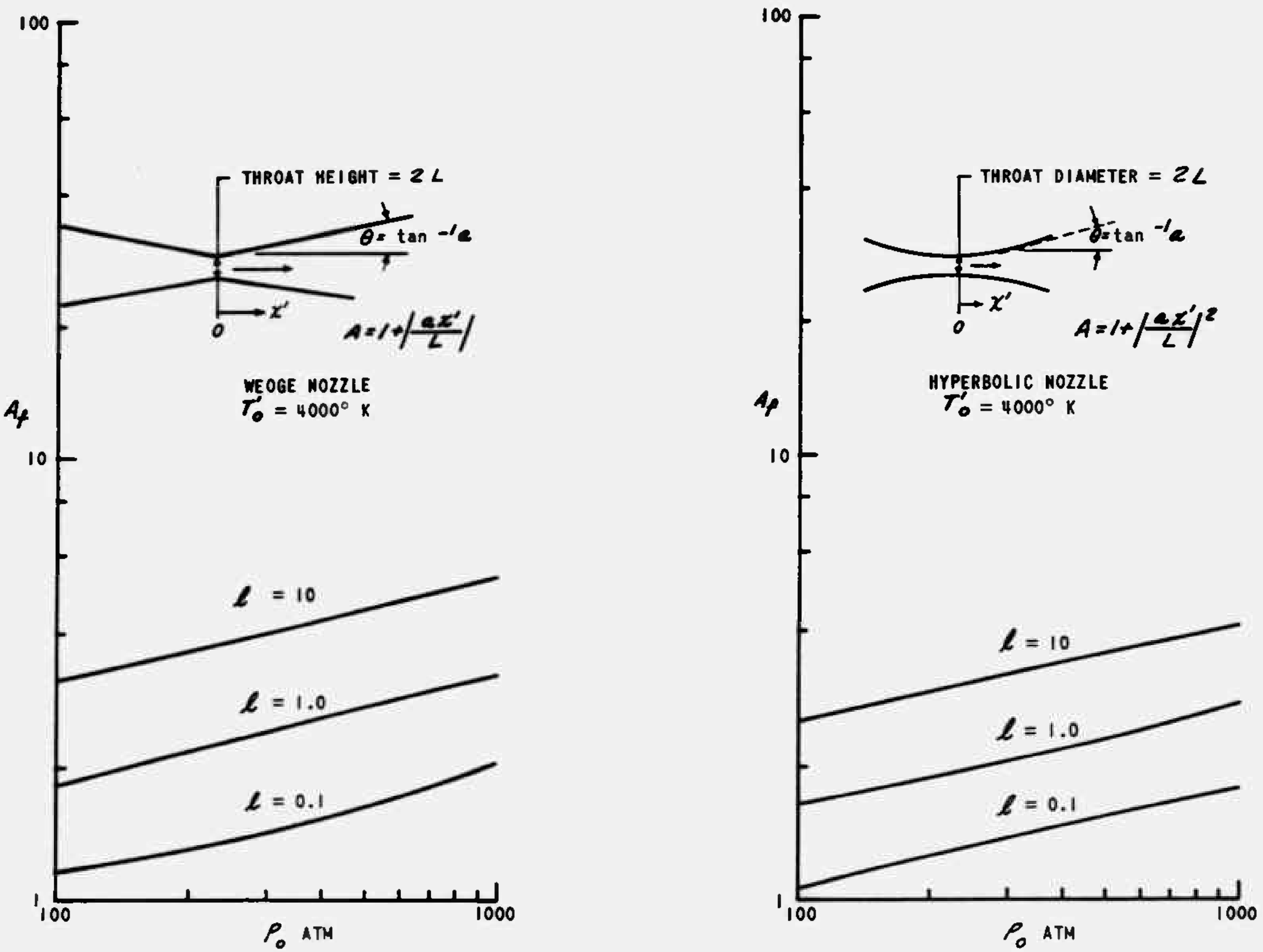


Figure 19 (a) EFFECT OF STAGNATION PRESSURE AND NOZZLE GEOMETRY ON THE AREA RATIO FOR FREEZING FOR A SIMPLIFIED AIR MODEL.

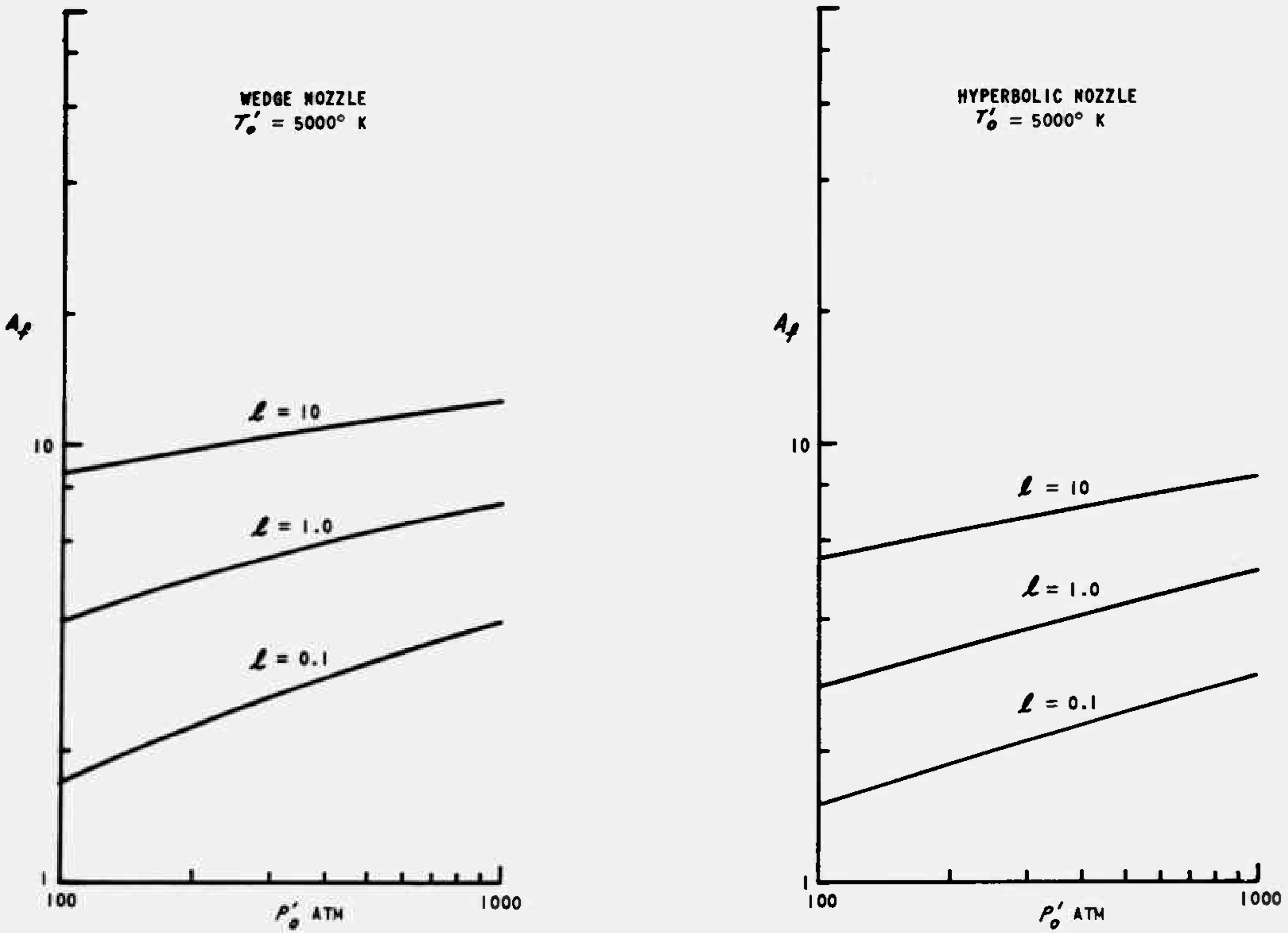


Figure 19 (b) EFFECT OF STAGNATION PRESSURE AND NOZZLE GEOMETRY ON THE AREA RATIO FOR FREEZING FOR A SIMPLIFIED AIR MODEL.

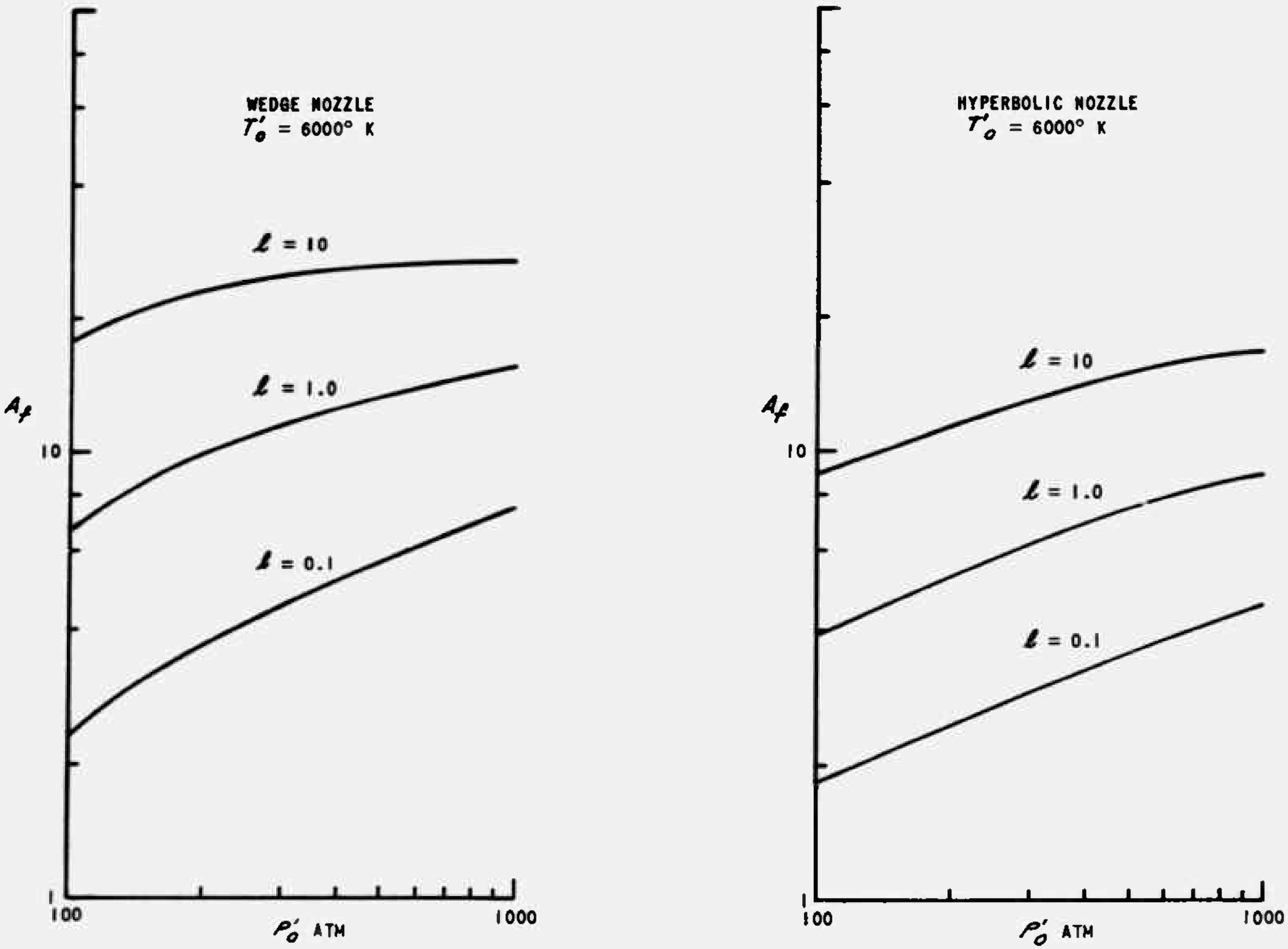


Figure 19 (c) EFFECT OF STAGNATION PRESSURE AND NOZZLE GEOMETRY ON THE AREA RATIO FOR FREEZING FOR A SIMPLIFIED AIR MODEL.

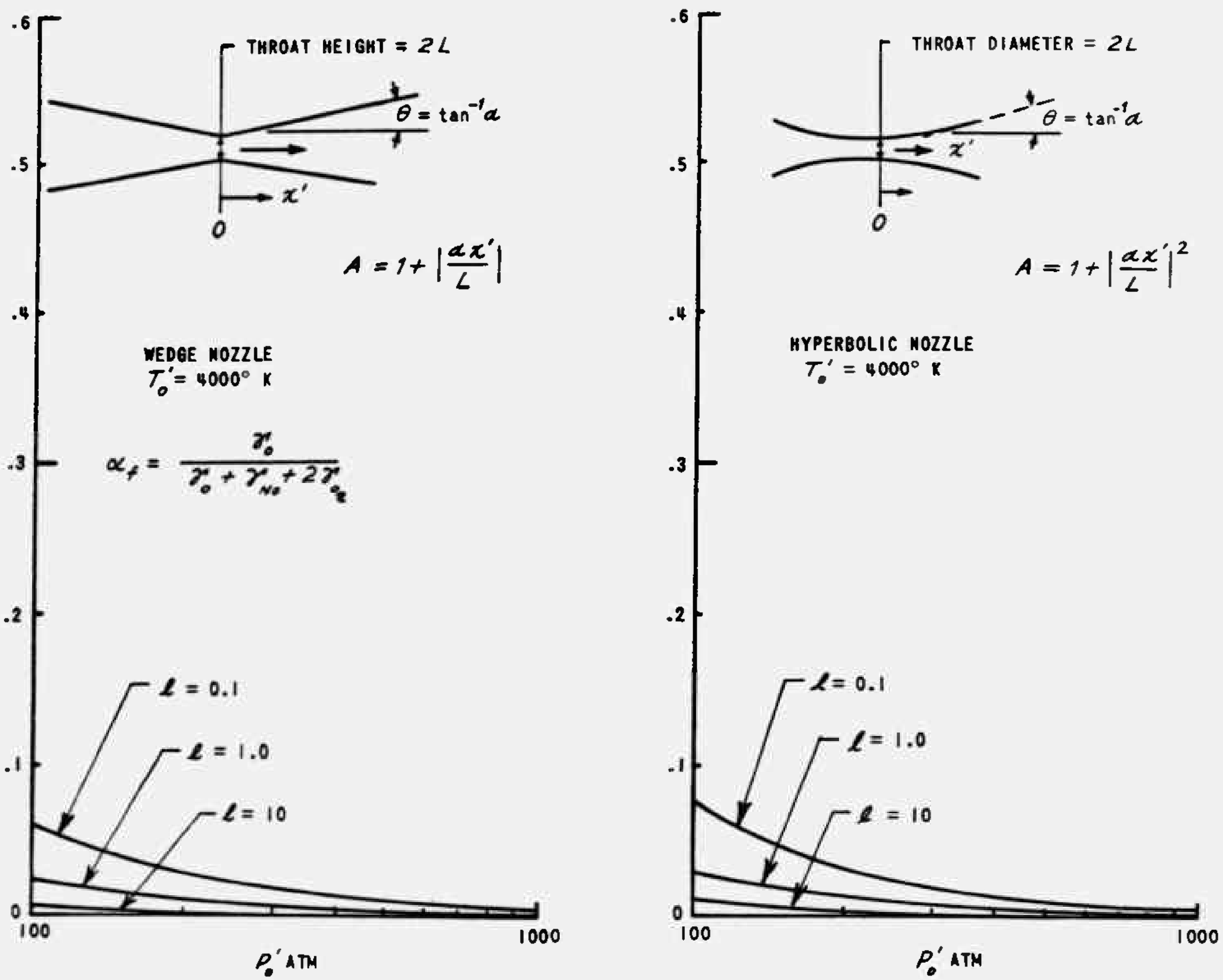


Figure 20 (a) EFFECT OF STAGNATION PRESSURE AND NOZZLE GEOMETRY ON THE FROZEN DEGREE OF OXYGEN DISSOCIATION FOR A SIMPLIFIED AIR MODEL.

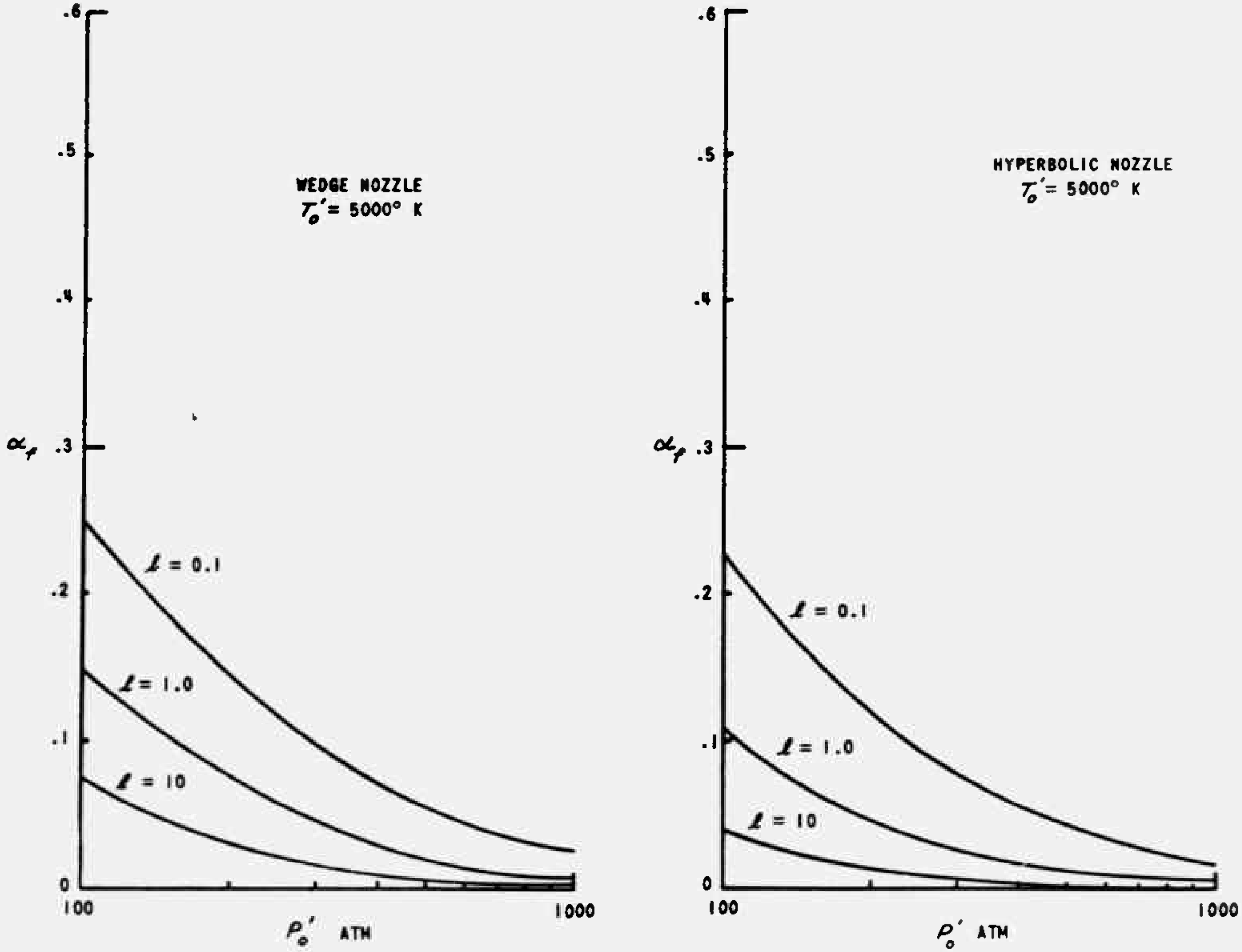


Figure 20 (b) EFFECT OF STAGNATION PRESSURE AND NOZZLE GEOMETRY ON THE FROZEN DEGREE OF OXYGEN OISSOCIATION FOR A SIMPLIFIED AIR MOOEL.

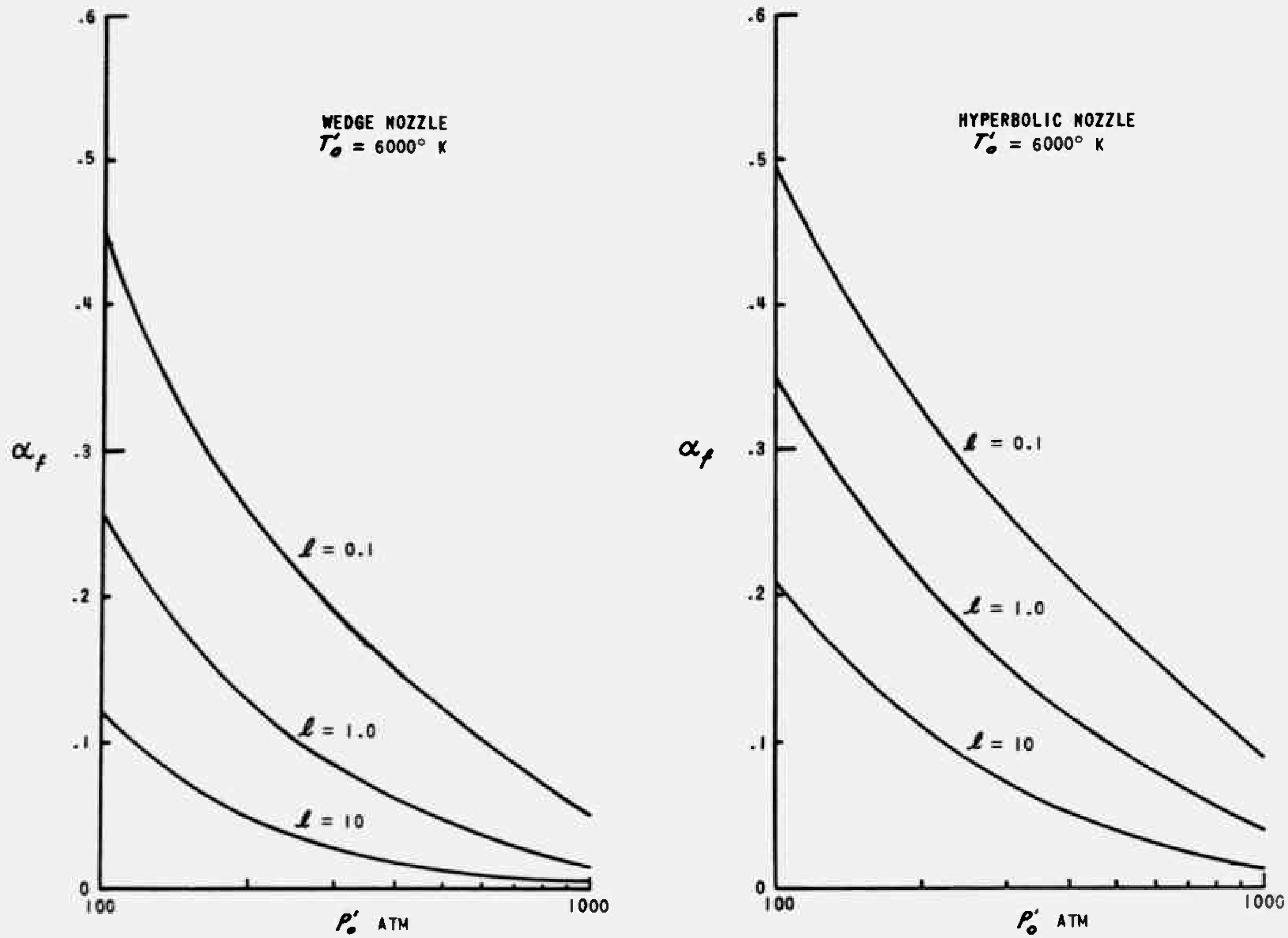


Figure 20 (c) EFFECT OF STAGNATION PRESSURE AND NOZZLE GEOMETRY ON THE FROZEN DEGREE OF OXYGEN DISSOCIATION FOR A SIMPLIFIED AIR MODEL.

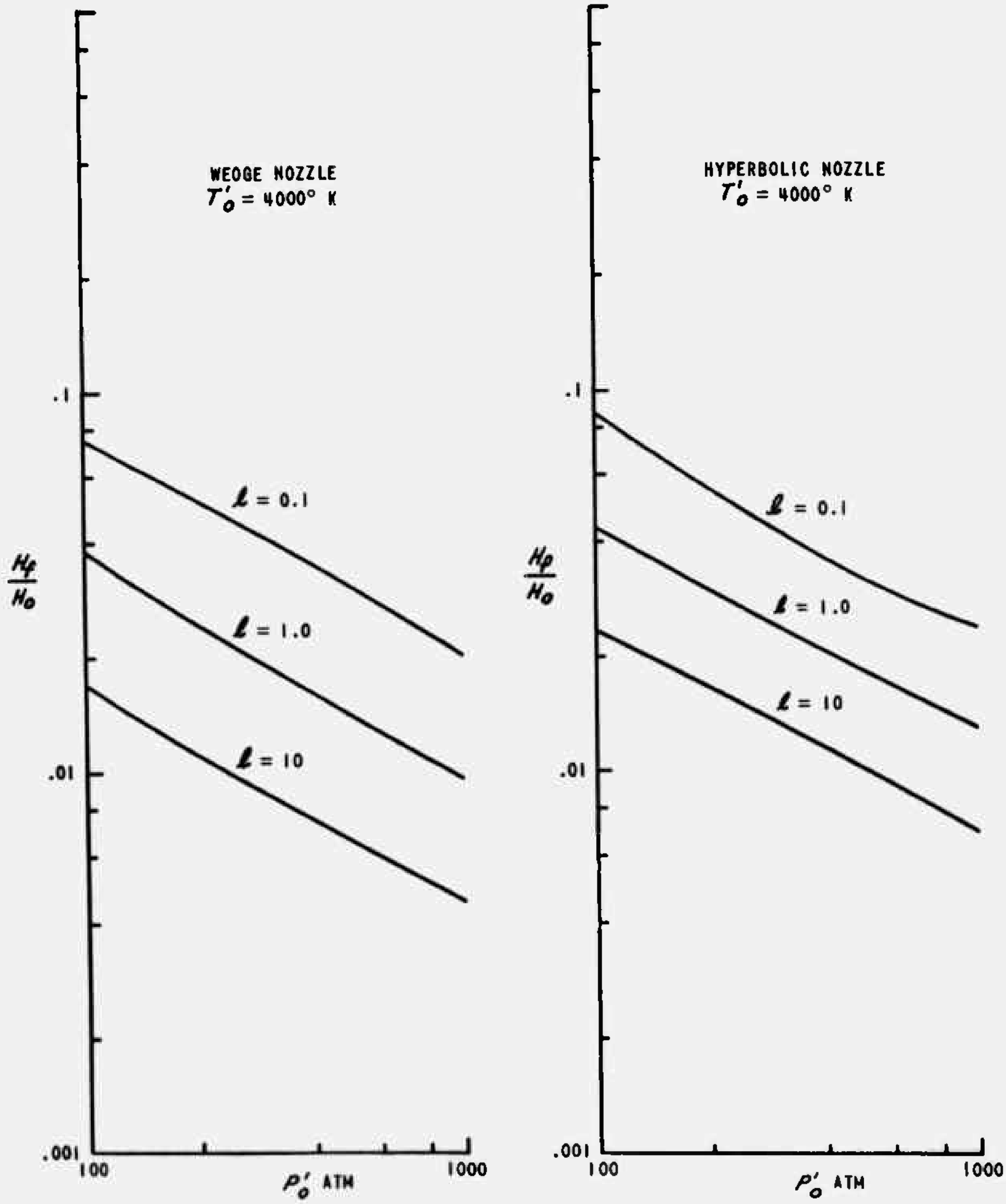


Figure 21 (a) EFFECT OF STAGNATION PRESSURE AND NOZZLE GEOMETRY ON THE FROZEN CHEMICAL ENERGY FOR A SIMPLIFIED AIR MODEL

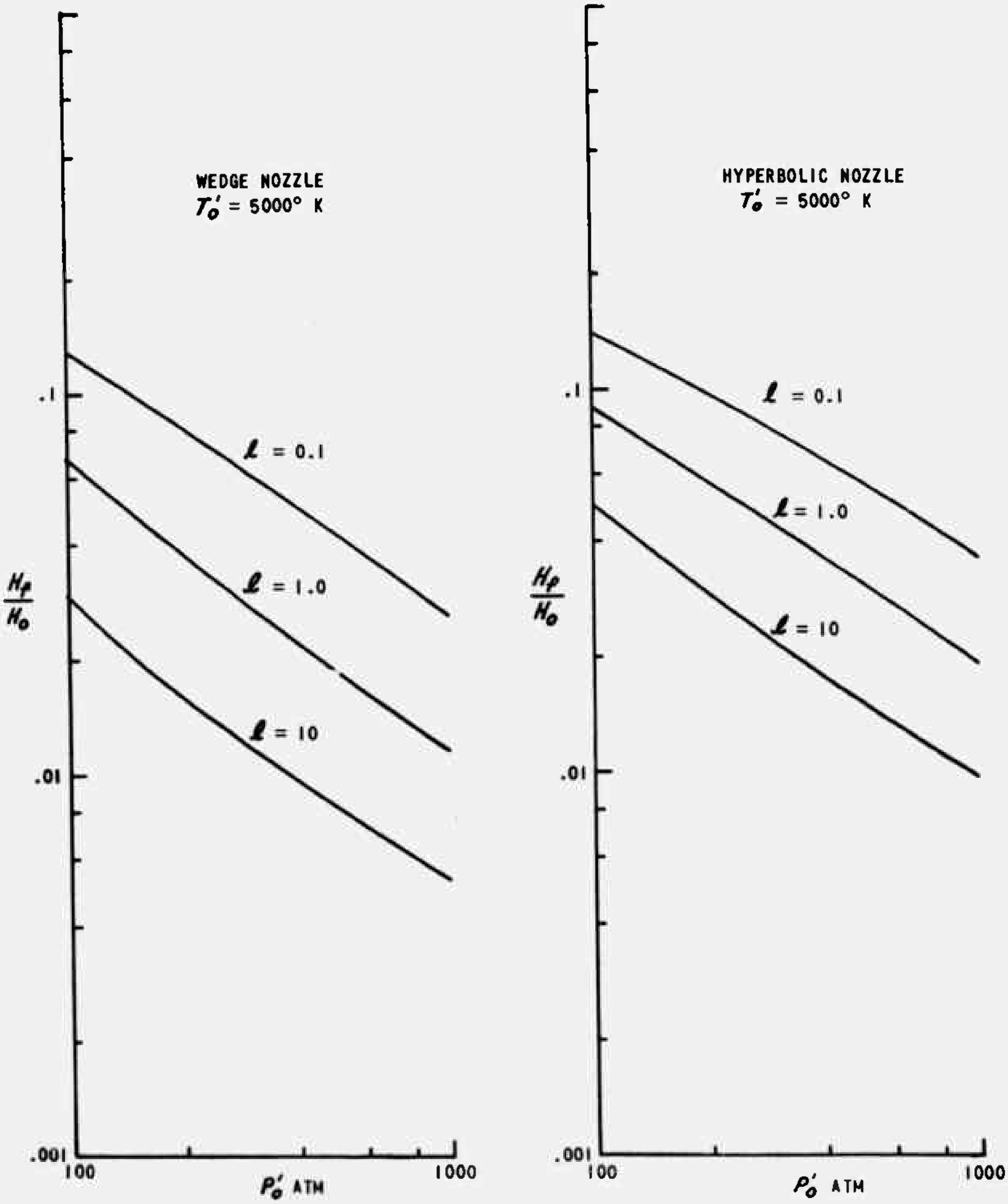


Figure 21 (b) EFFECT OF STAGNATION PRESSURE AND NOZZLE GEOMETRY ON THE FROZEN CHEMICAL ENERGY FOR A SIMPLIFIED AIR MODEL

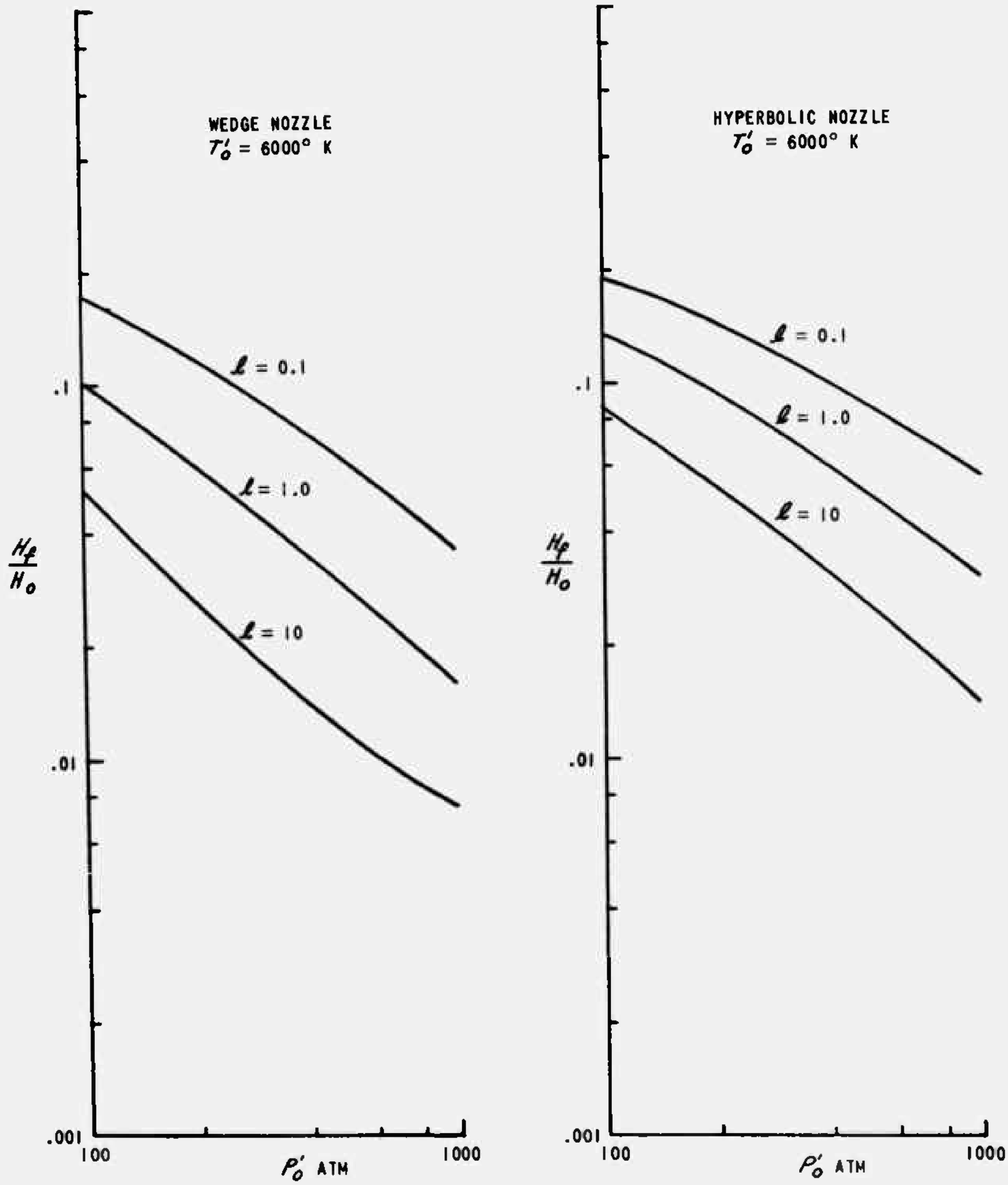


Figure 21 (c) EFFECT OF STAGNATION PRESSURE AND NOZZLE GEOMETRY ON THE FROZEN CHEMICAL ENERGY FOR A SIMPLIFIED AIR MODEL

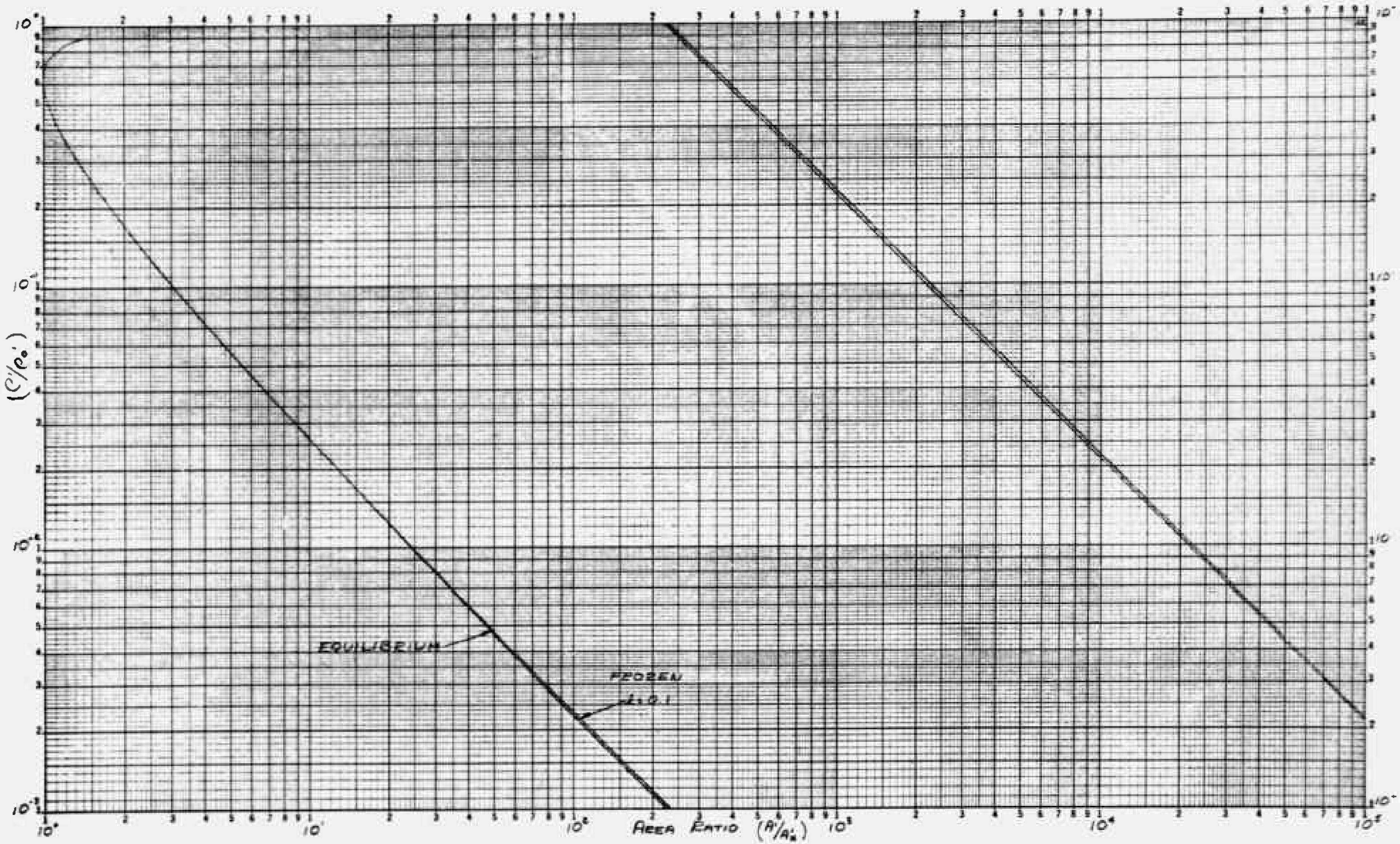


FIGURE NO 33.2 HYPERBOLIC NOZZLE $T_o' = 4000°K$ $P_o' = 100$ ATM

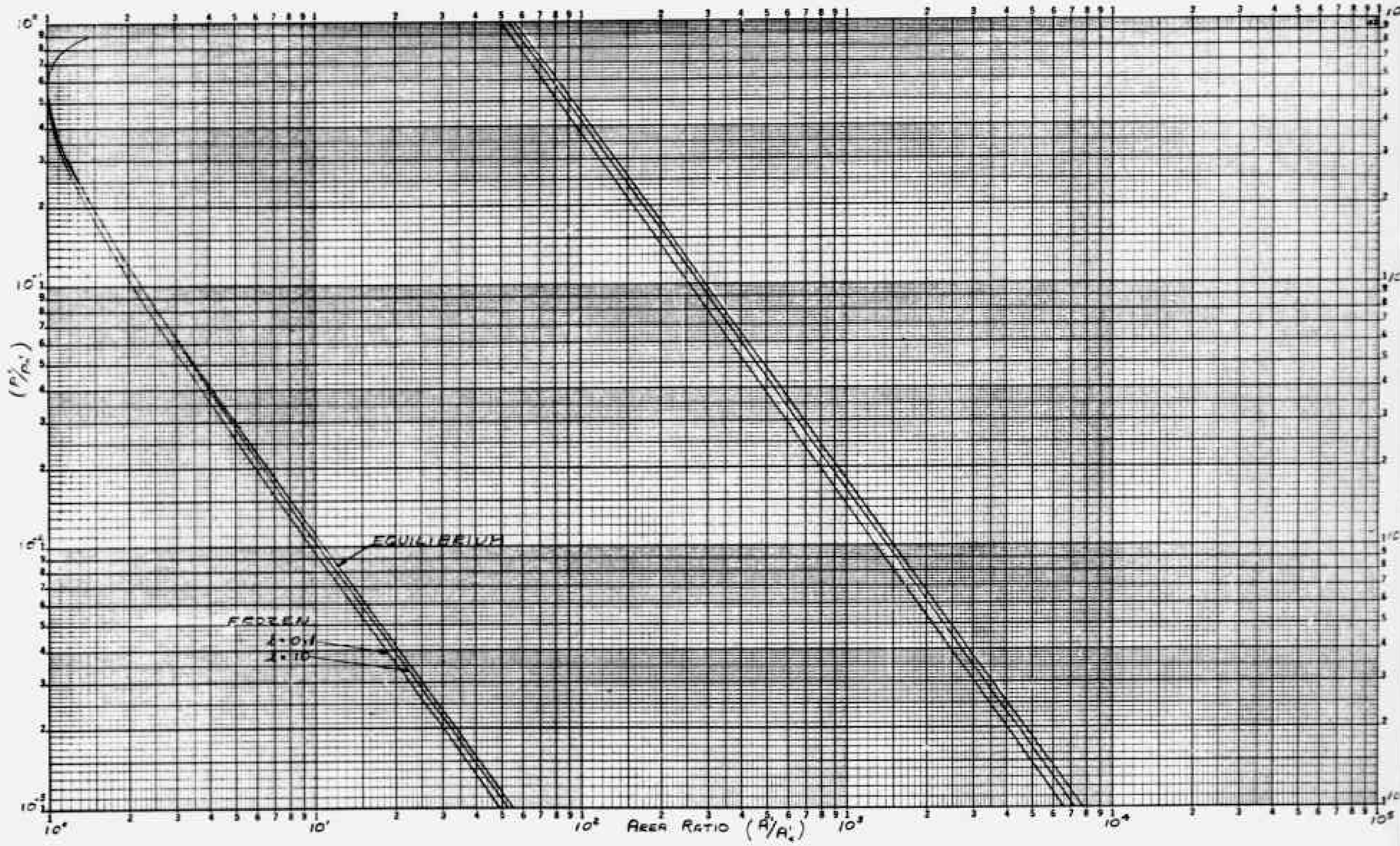


FIGURE NO 22 b HYPERBOLIC NOZZLE $T_0' = 4000°K$ $P_0' = 100$ ATM

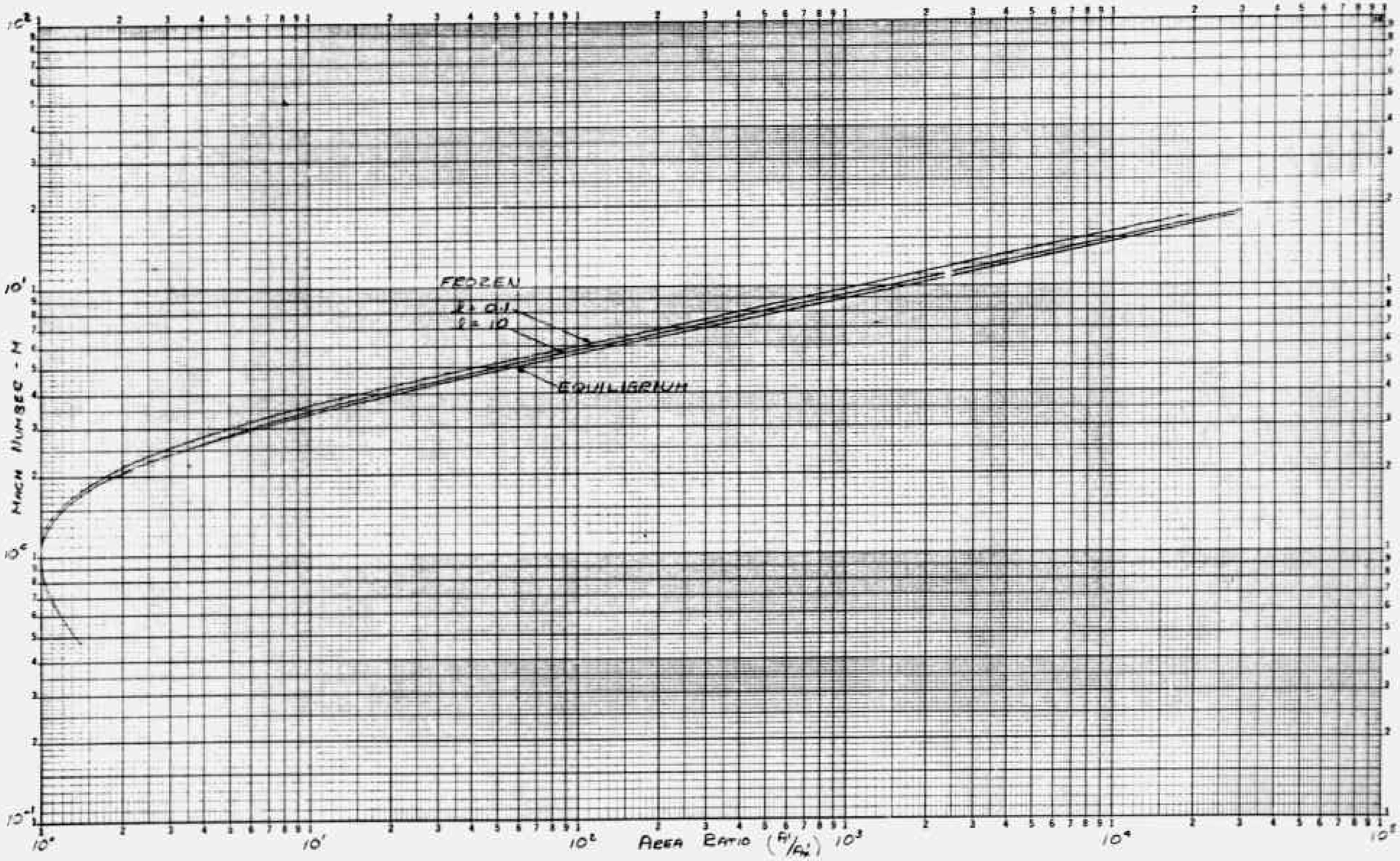


FIGURE 110 [illegible] HYPERBOLIC NOZZLE $T_0' = 4000°K$ $P_0' = 100$ ATM

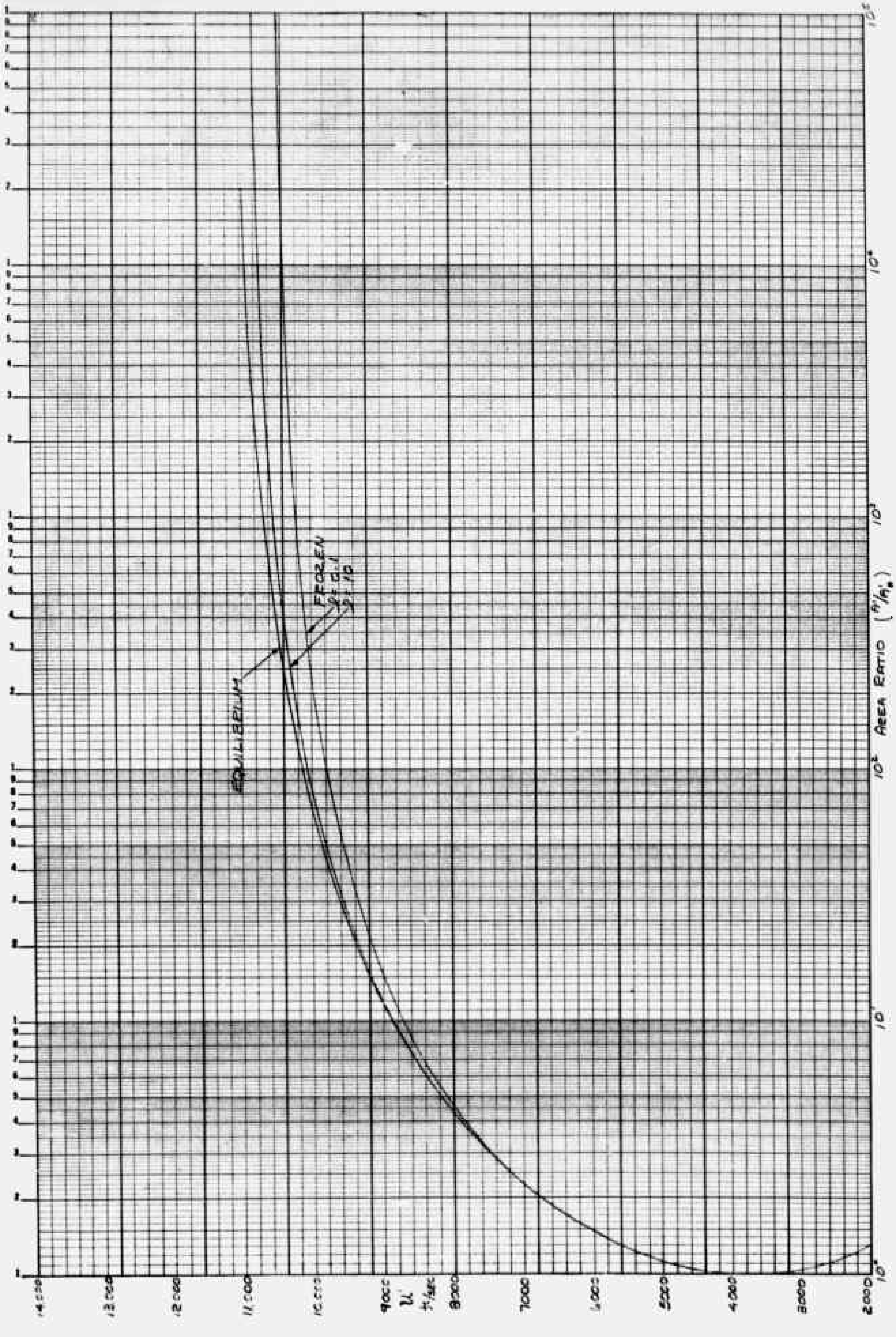


FIGURE NO. 22d HYPERBOLIC NOZZLE $T_0' = 4000°K$ $P_0' = 100$ ATM

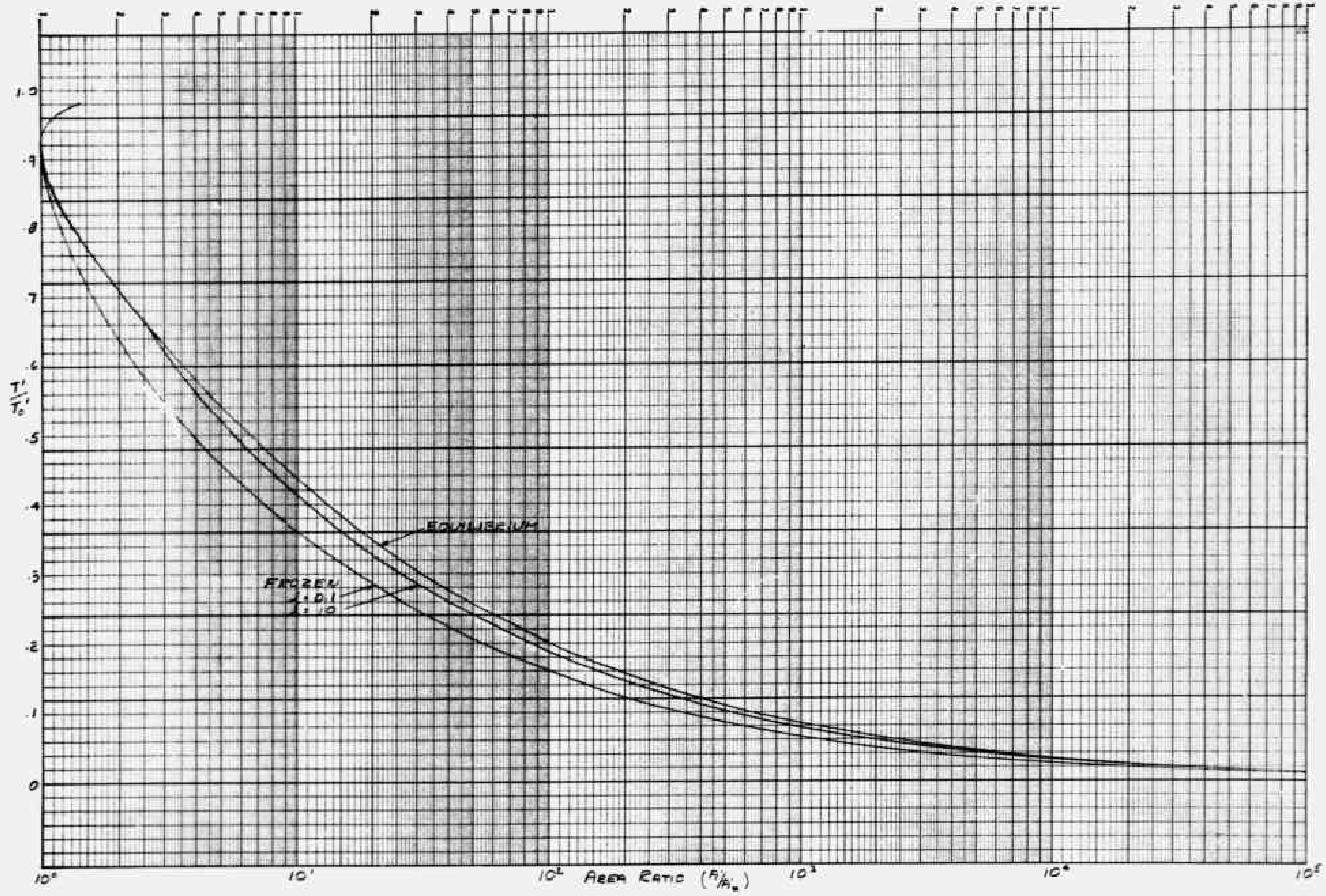


FIGURE NO. 22e HYPERBOLIC NOZZLE T_o' = 4000°K P_o' = 100 ATM

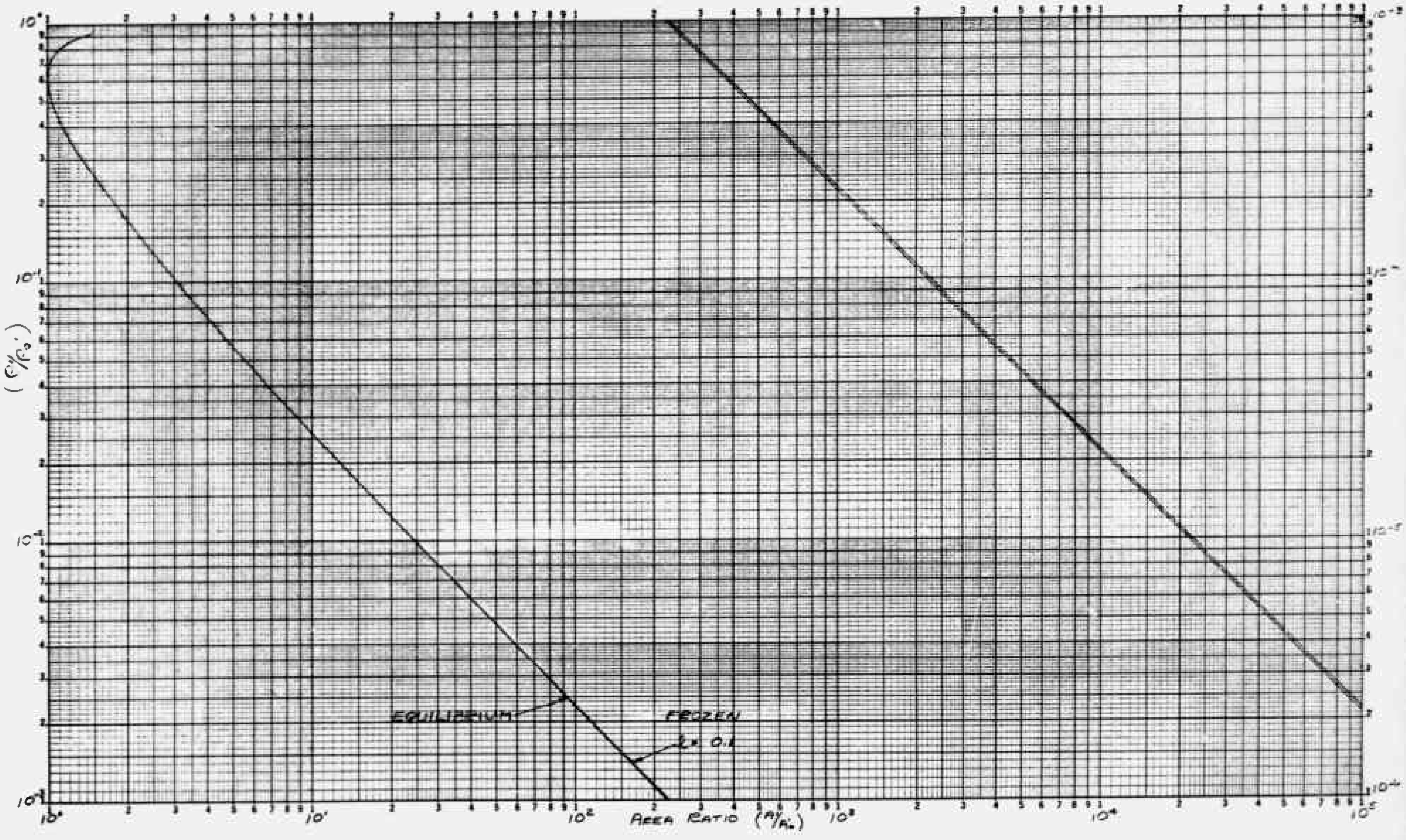


FIGURE NO. 23a HYPERBOLIC NOZZLE $T_0' = 4000°K$ $P_0' = 300$ ATM

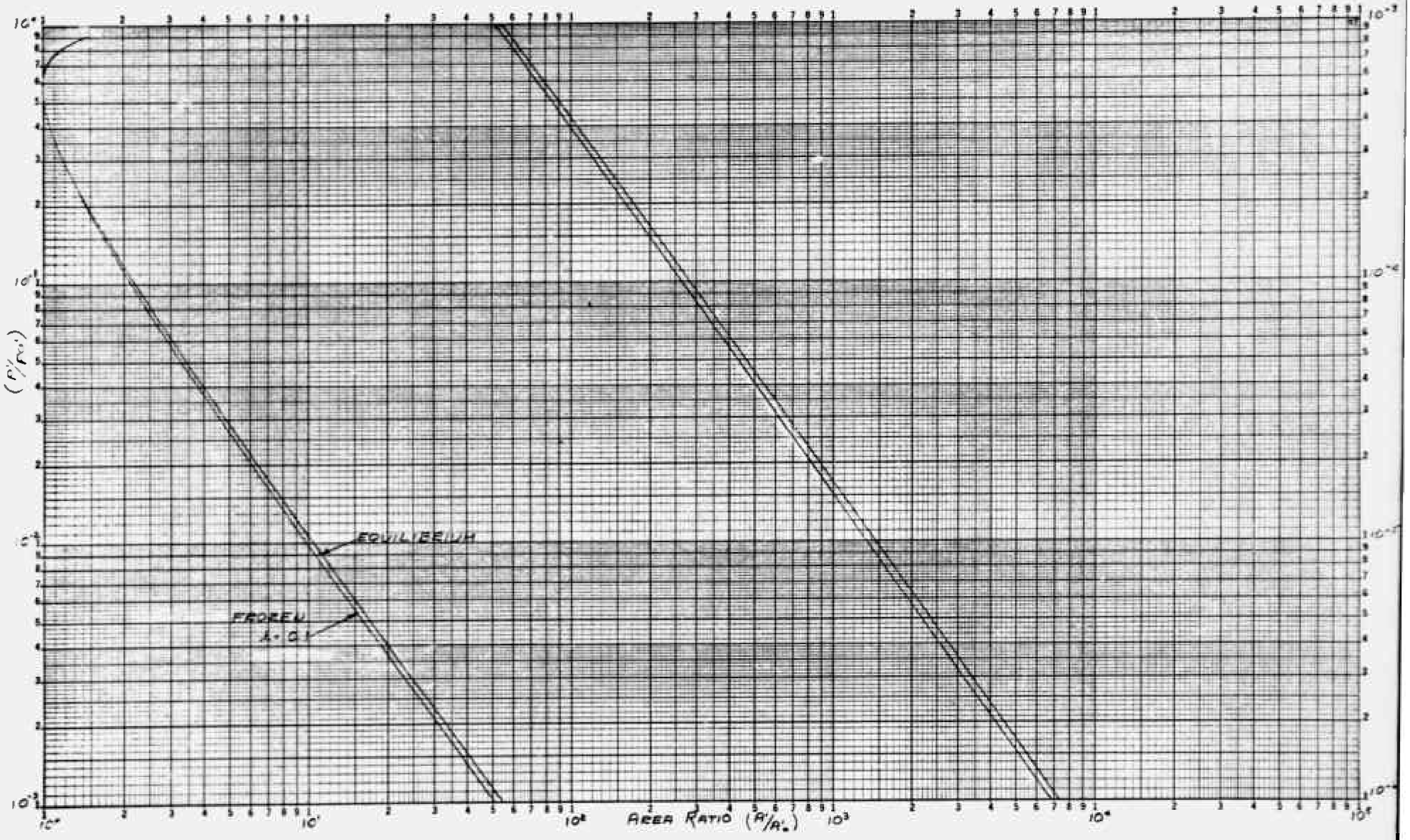


FIGURE NO. 23b HYPERBOLIC NOZZLE $T'_0 = 4000°K$ $P'_0 = 300$ ATM

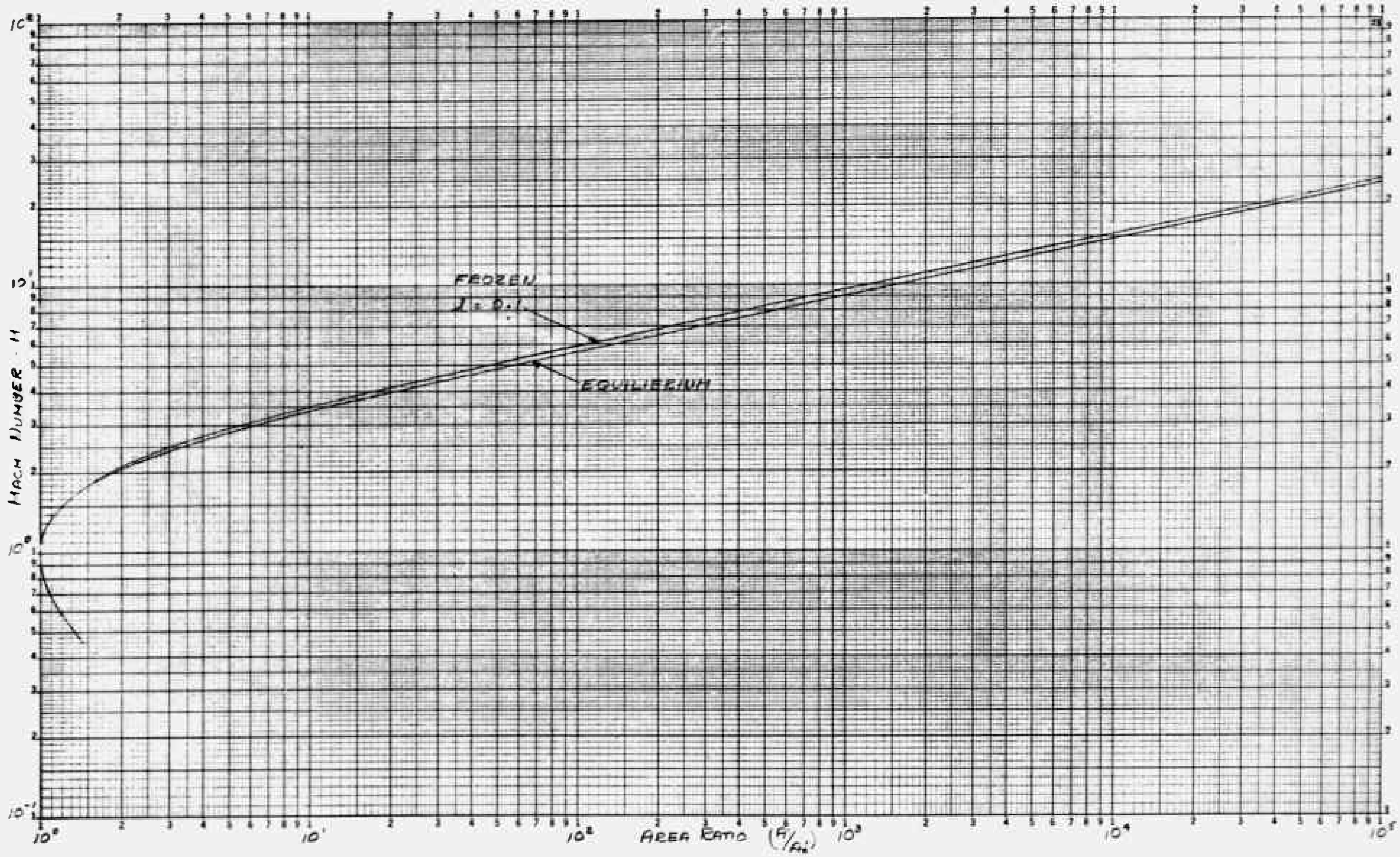


FIGURE NO. 23c HYPERBOLIC NOZZLE $T_0' = 4000°K$ $P_0' = 300$ ATM

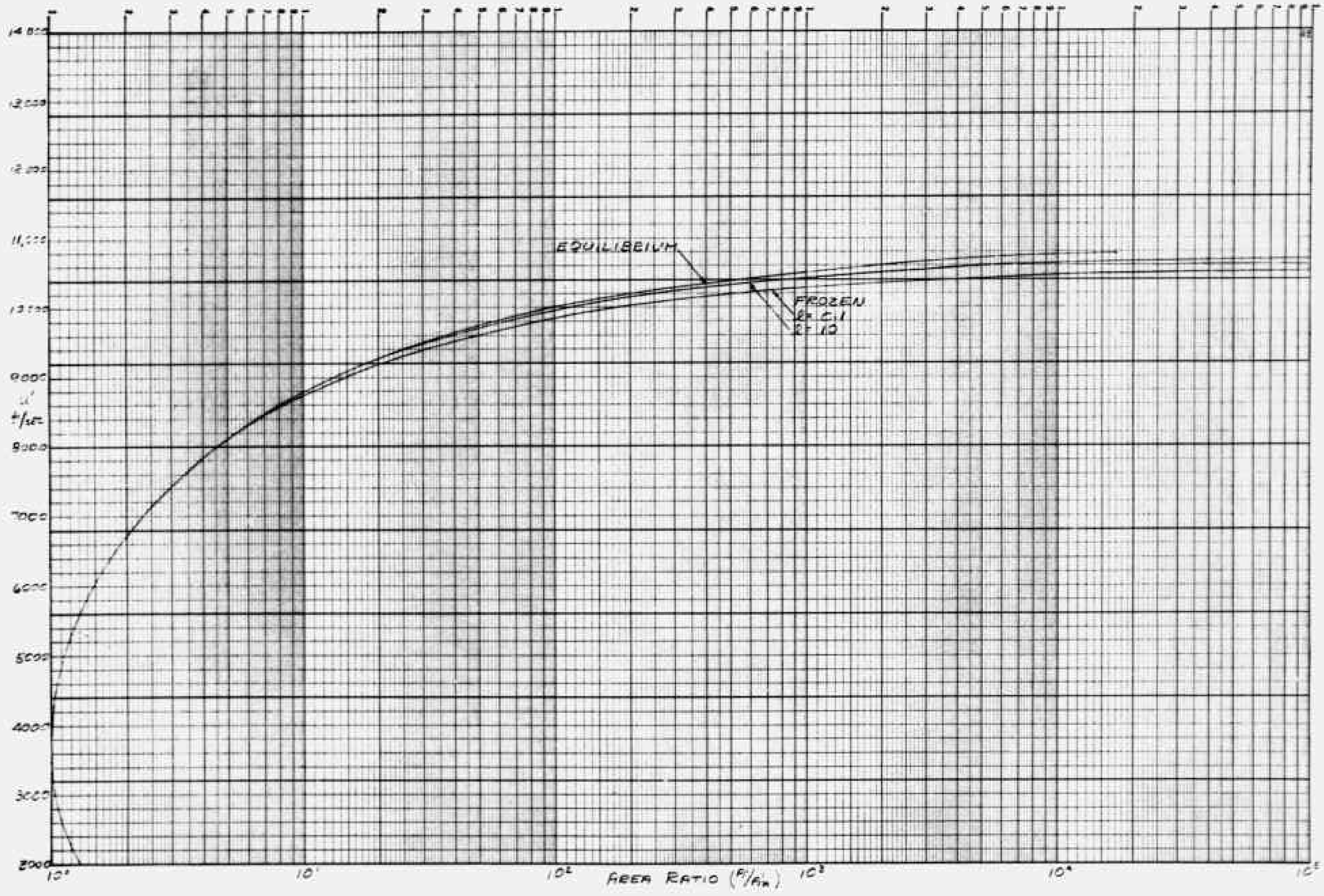


FIGURE NO. 23d [illegible] NOZZLE $T_o' = 4000°K$ $P_o' = 300$ ATM

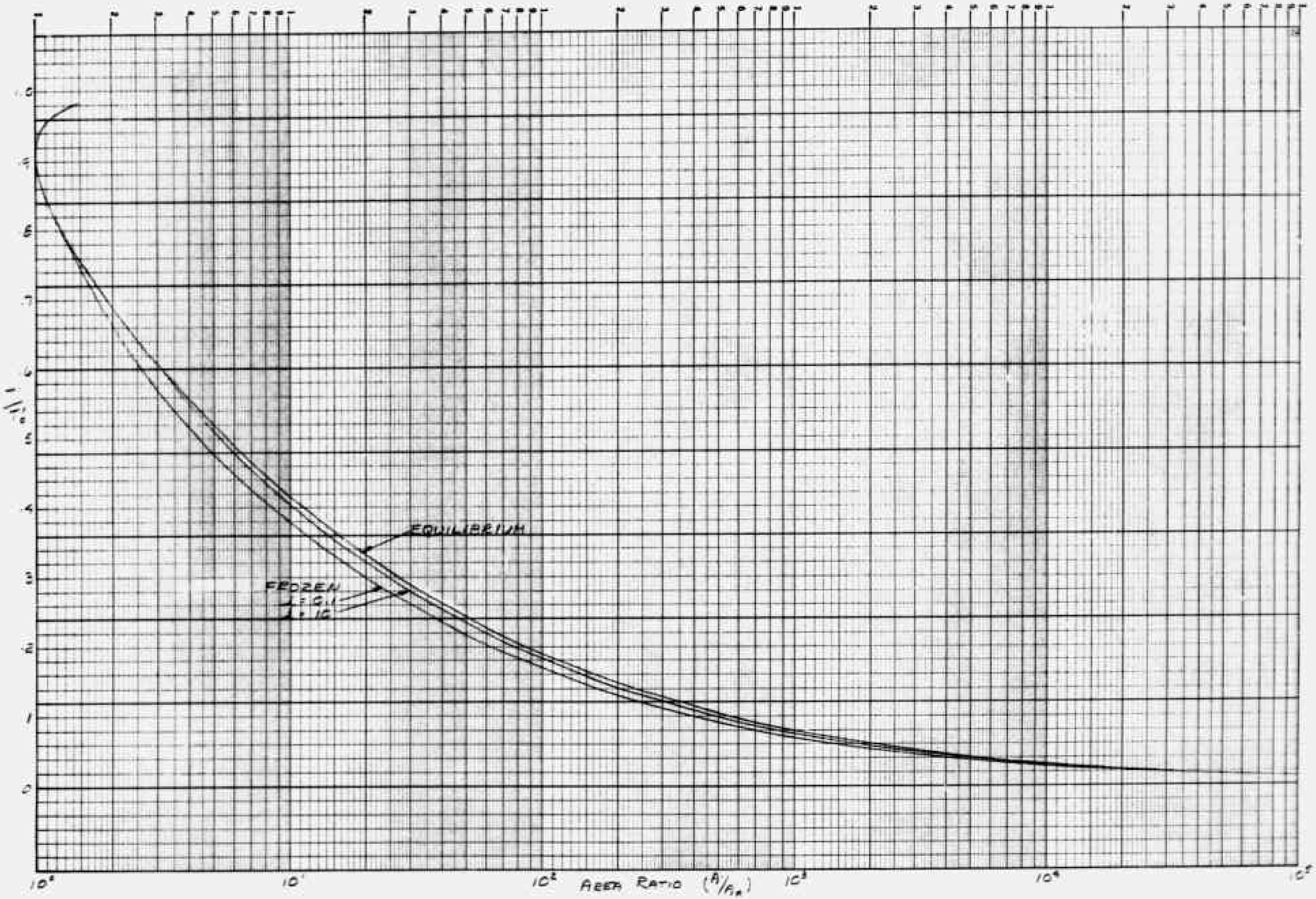


FIGURE NO. 23e HYPERBOLIC NOZZLE $T_0' = 4000°K$ $P_0' = 300$ ATM

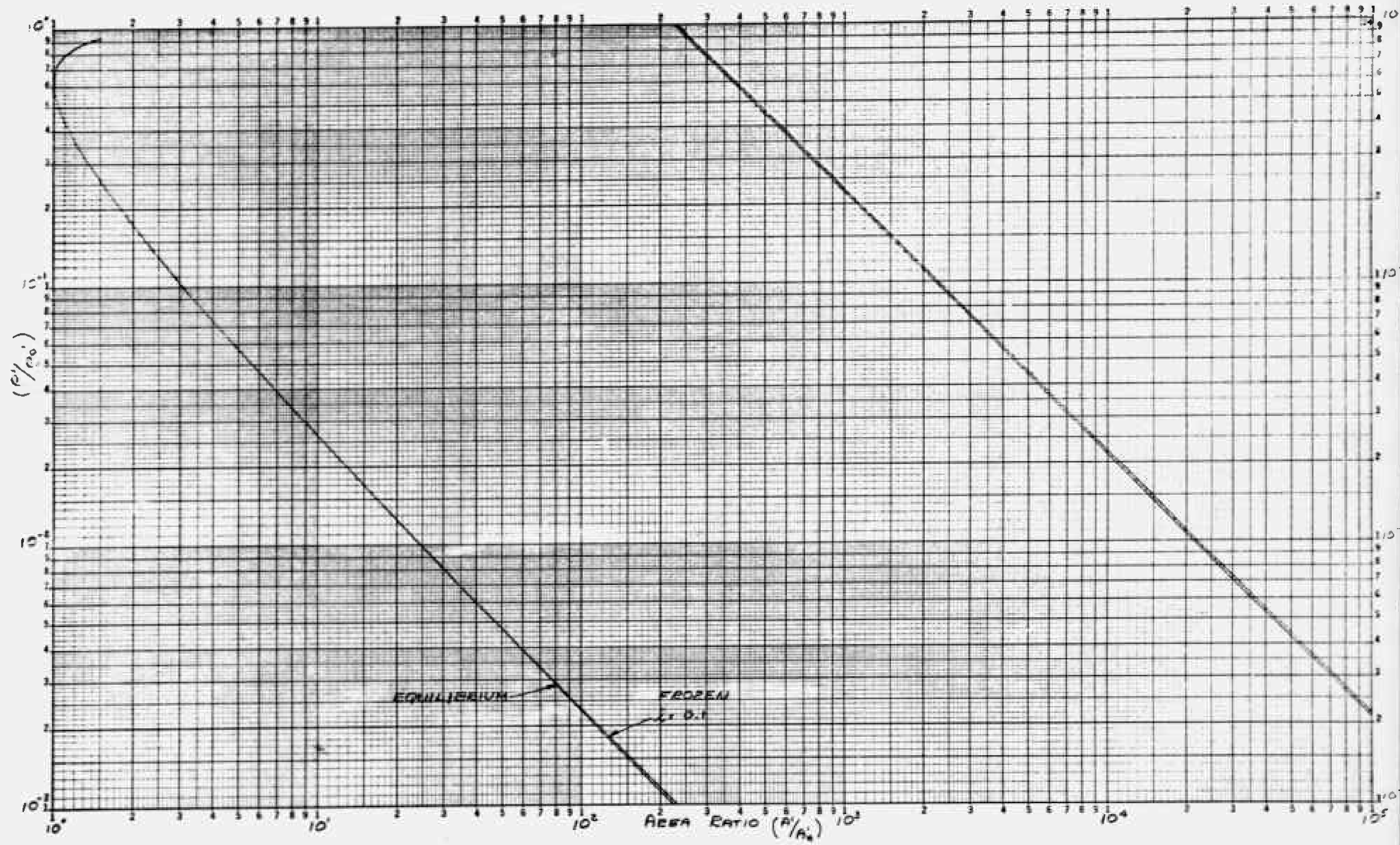


FIGURE NO. 242. HYPERBOLIC NOZZLE $T_0' = 4000°K$ $P_0' = 1000$ ATM

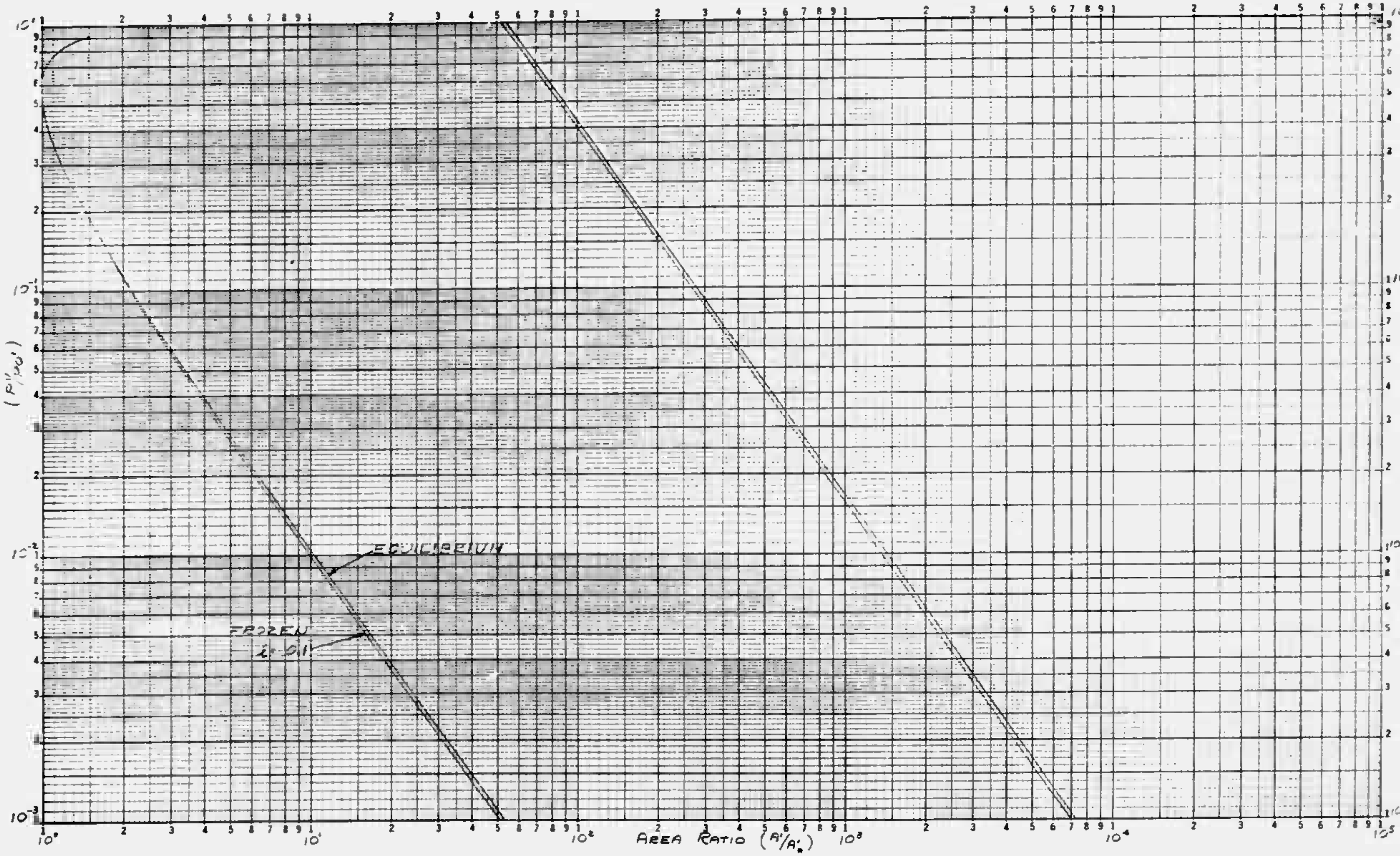


FIGURE NO. 24b HYPERBOLIC NOZZLE $T_0' = 4000°K$ $P_0' = 1000$ ATM

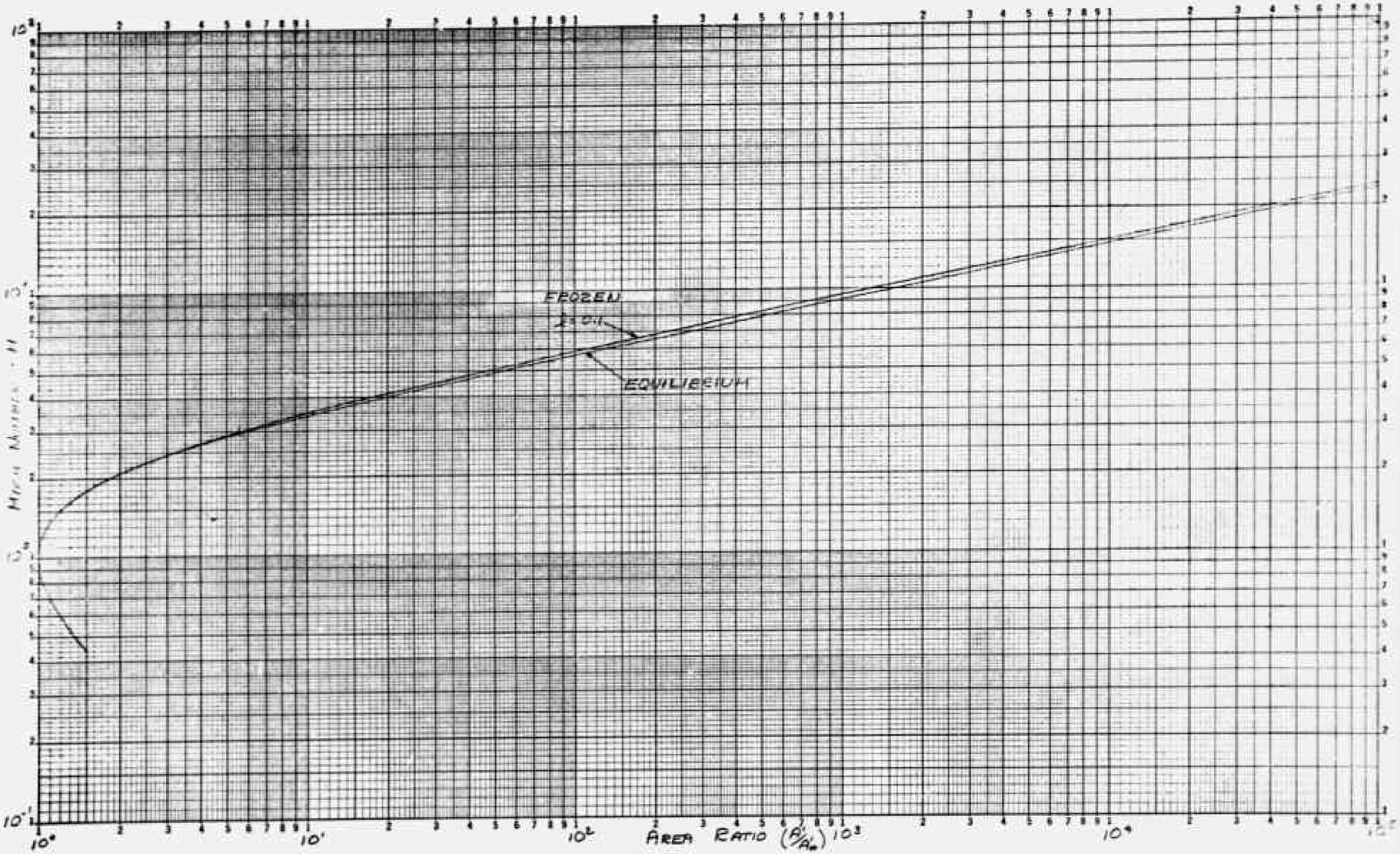


FIGURE NO. 24c HYPERBOLIC NOZZLE $T_0' = 4000°K$ $P_c' = 1000$ ATM

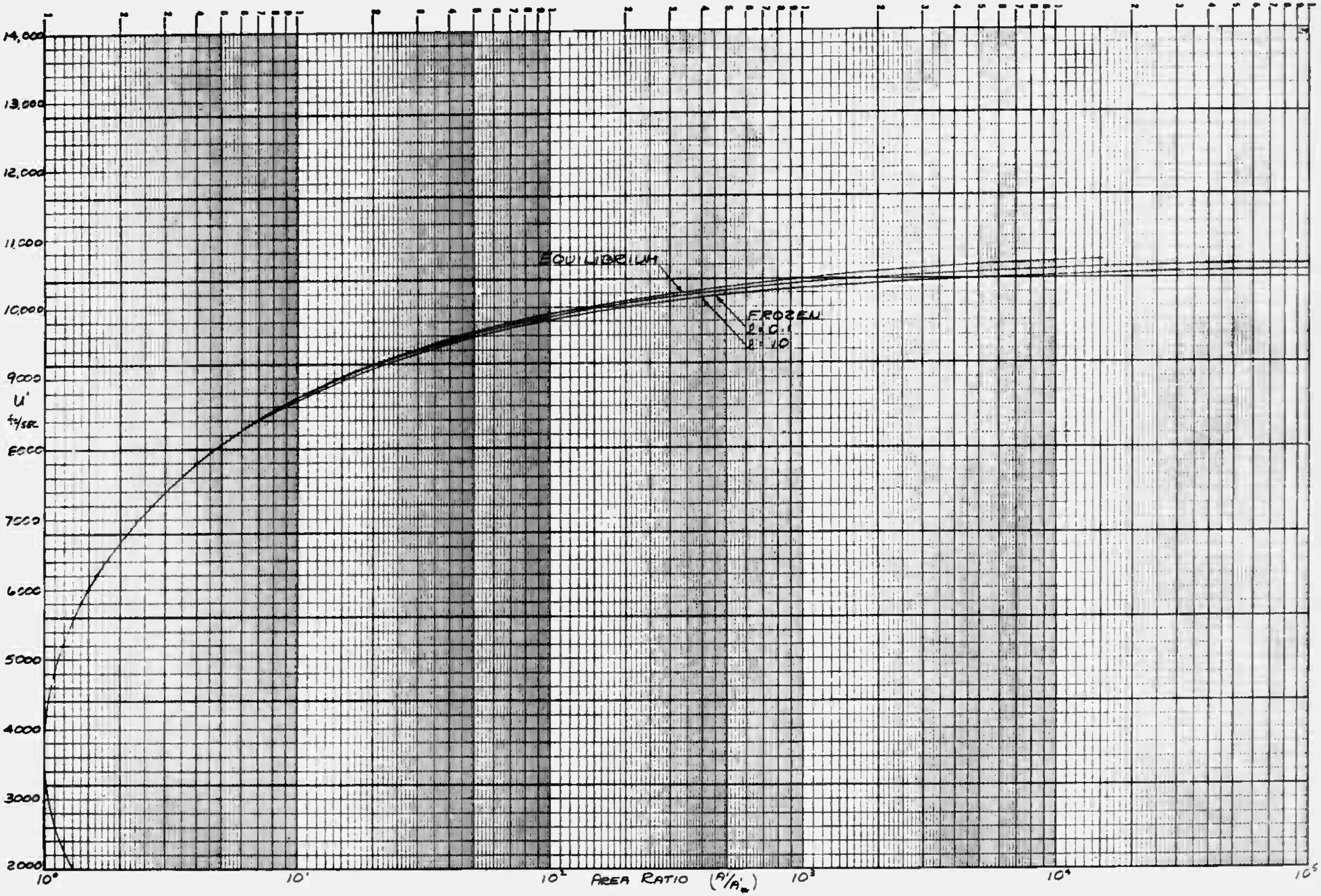


FIGURE NO. 24d HYPERBOLIC NOZZLE $T_0' = 4000°K$ $P_0' = 1000$ ATM

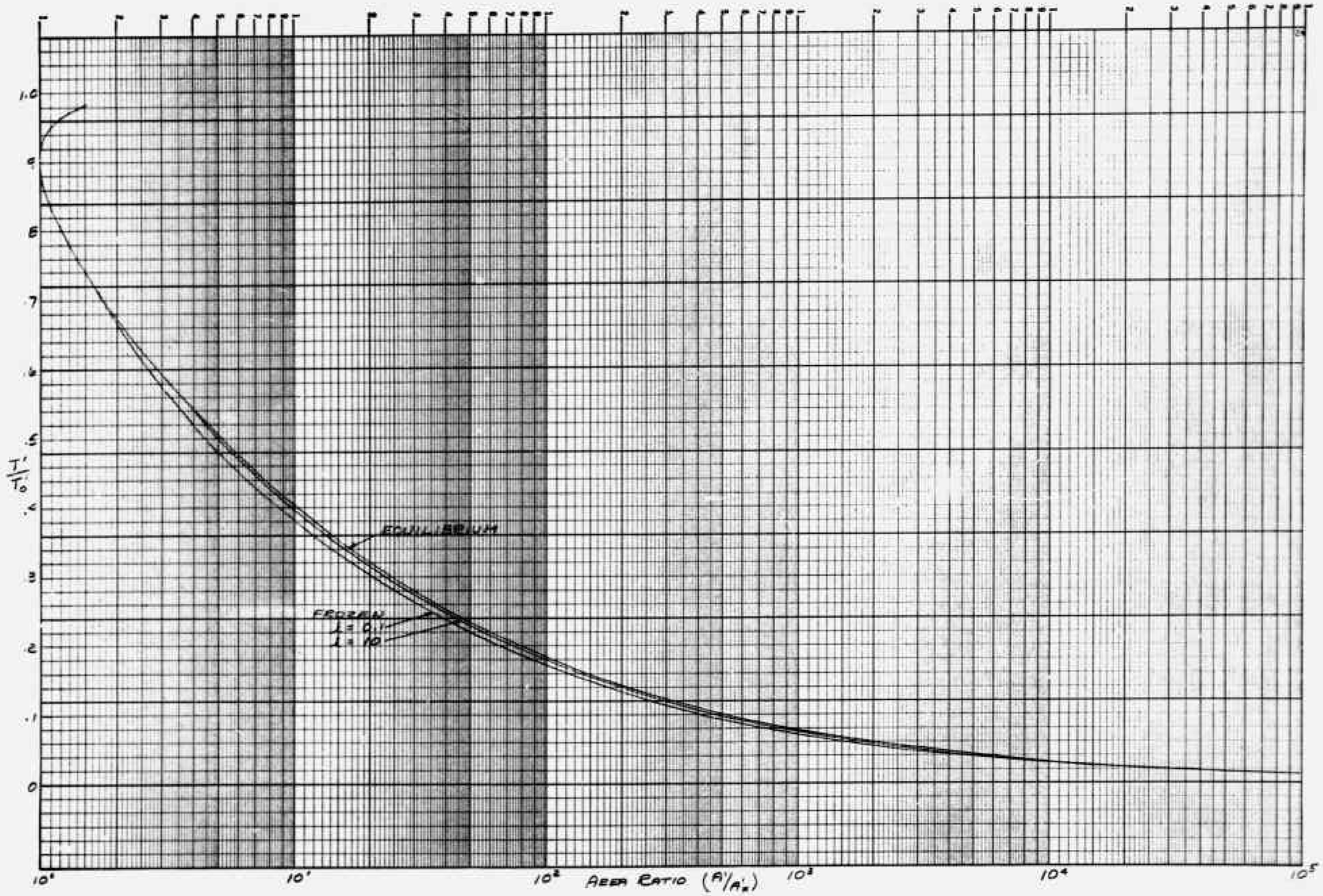


FIGURE NO. 24e HYPERSONIC NOZZLE $T_0' = 4000°K$ $P_0' = 1000$ ATM

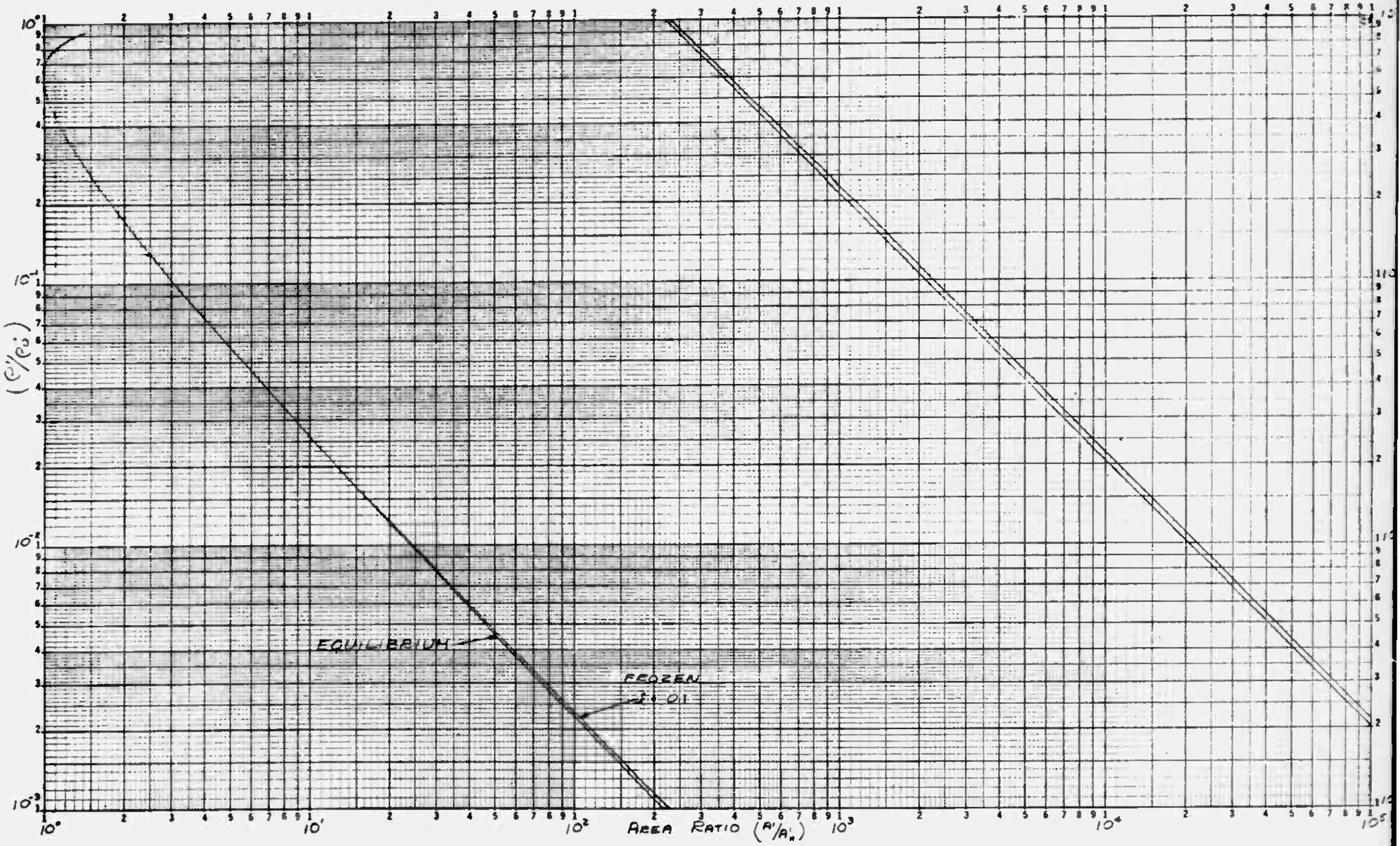


FIGURE NO. 25a HYPERBOLIC NOZZLE $T'_0 = 5000°K$ $P'_0 = 100\,ATM$

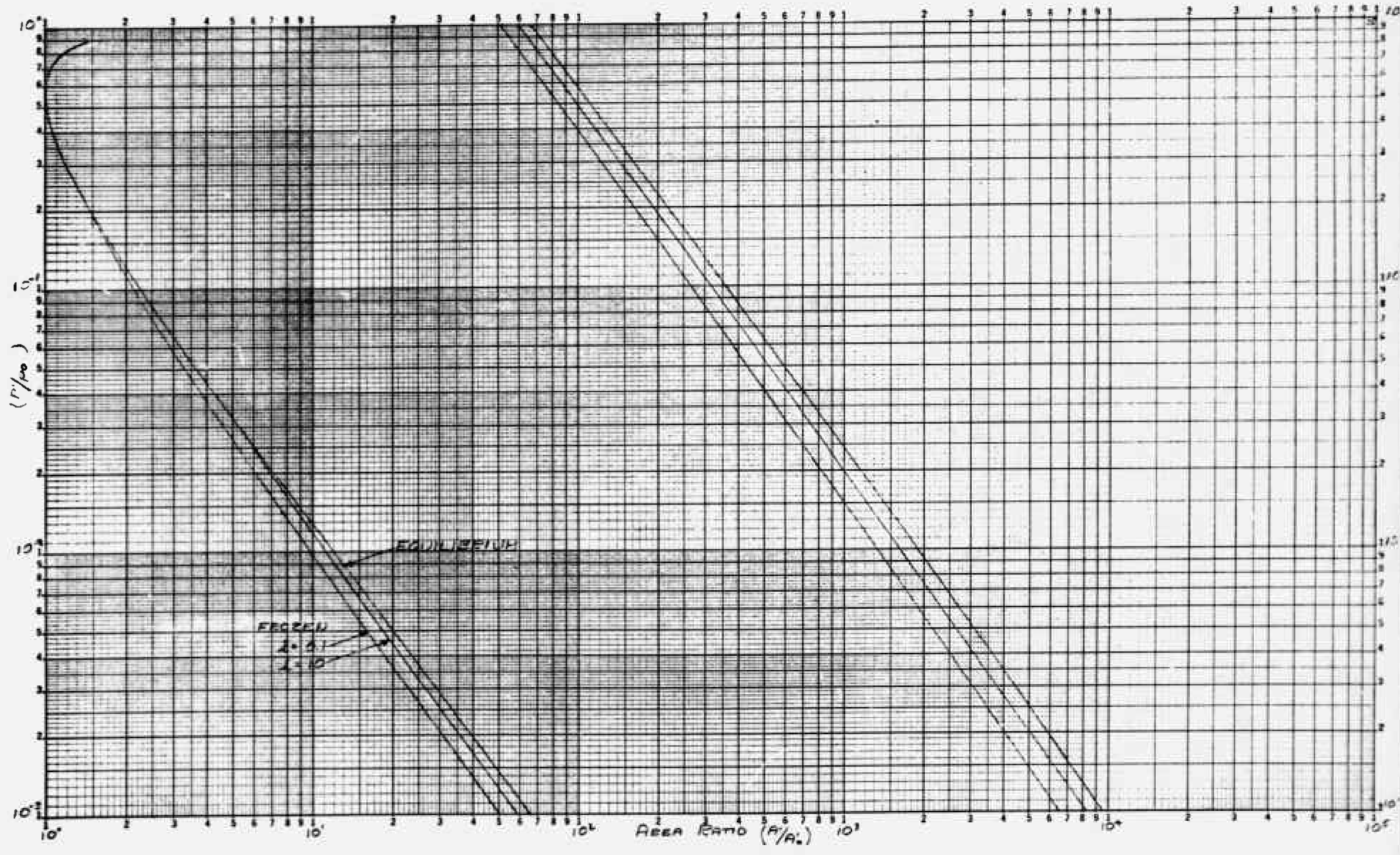


FIGURE NO. 25b HYPERBOLIC NOZZLE $T_0' = 5000°K$ $P_0' = 100$ ATM

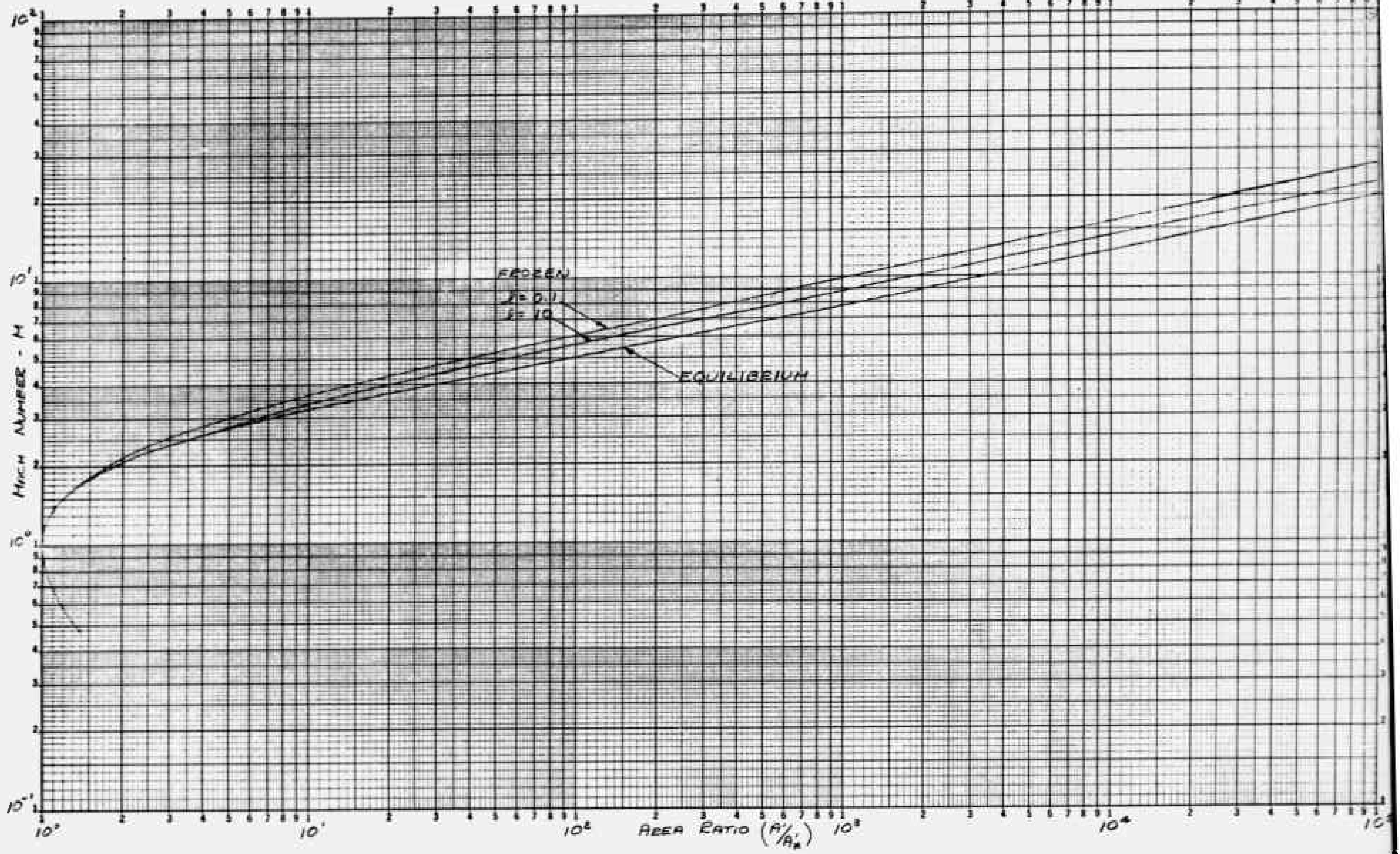


FIGURE NO. 25c HYPERBOLIC NOZZLE $T_0' = 5000°K$ $P_0' = 100$ ATM

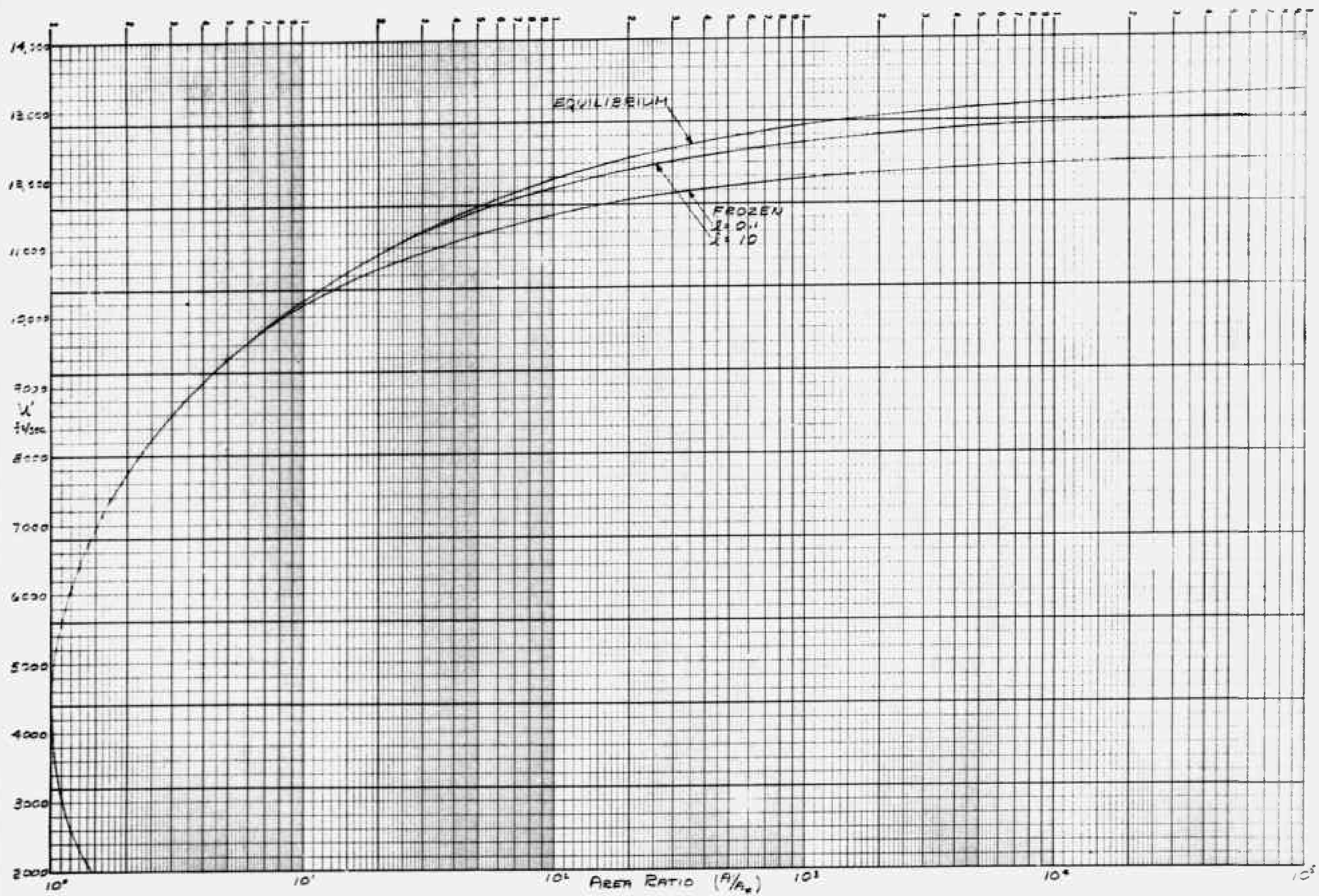


FIGURE NO. 25d HYPERBOLIC [illegible] $T_o = 5000°K$ [illegible]

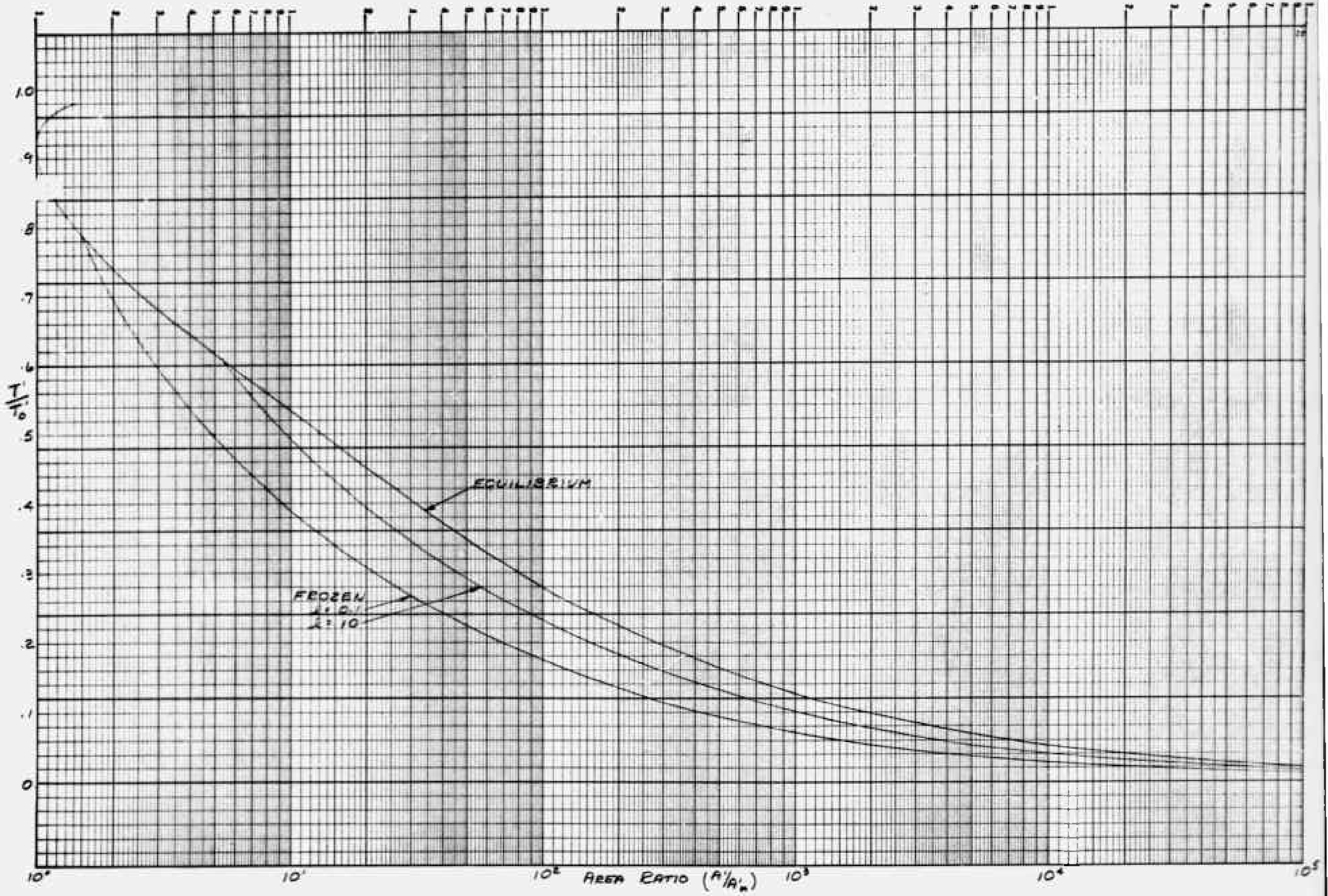


FIGURE NO. 25e HYPERBOLIC NOZZLE $T'_0 = 5000°K$ $P'_0 = 100$ ATM

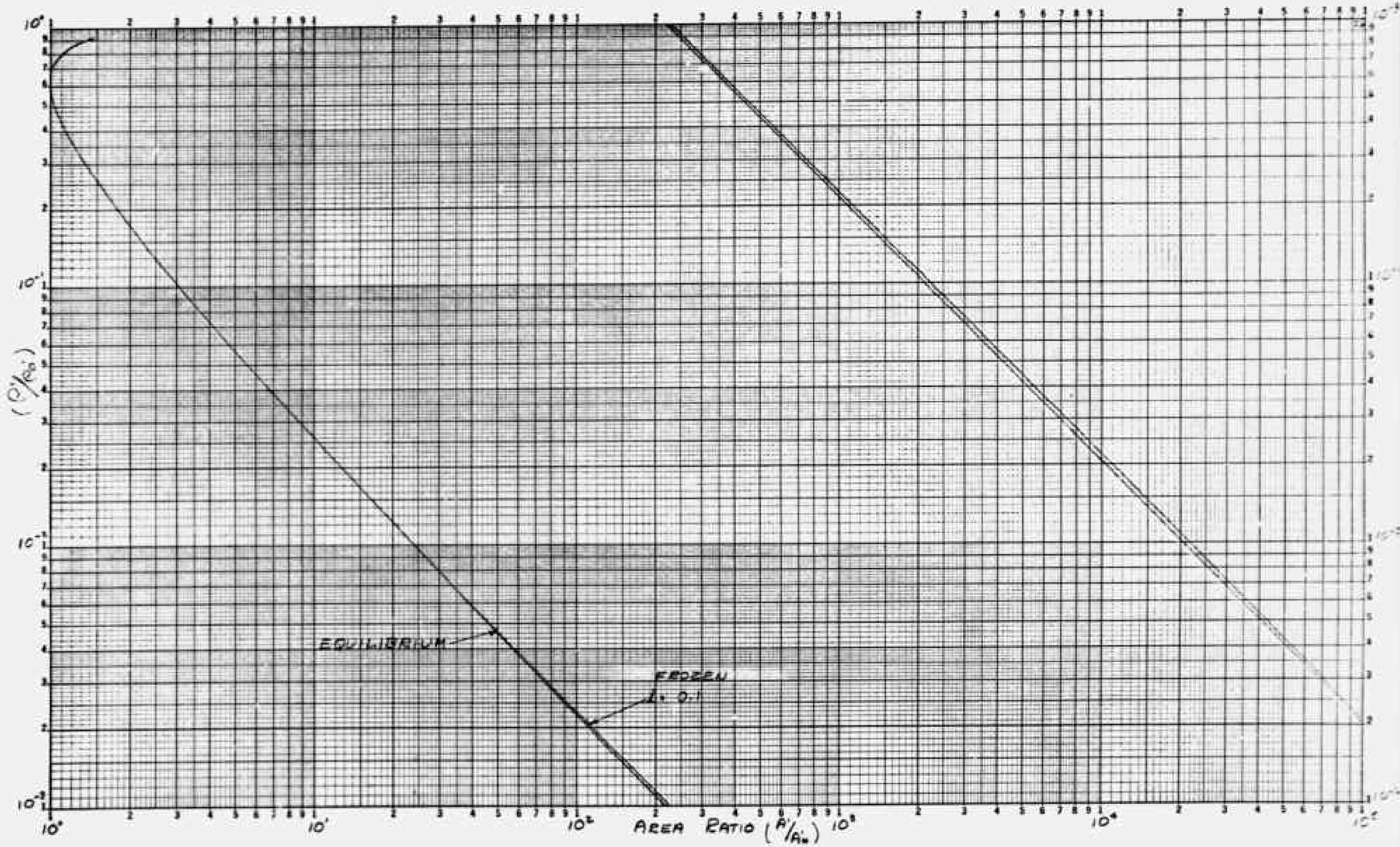


FIGURE NO. 26a HYPERSONIC NOZZLE $T_0' = 5000°K$ $P_0' = 200$ ATM

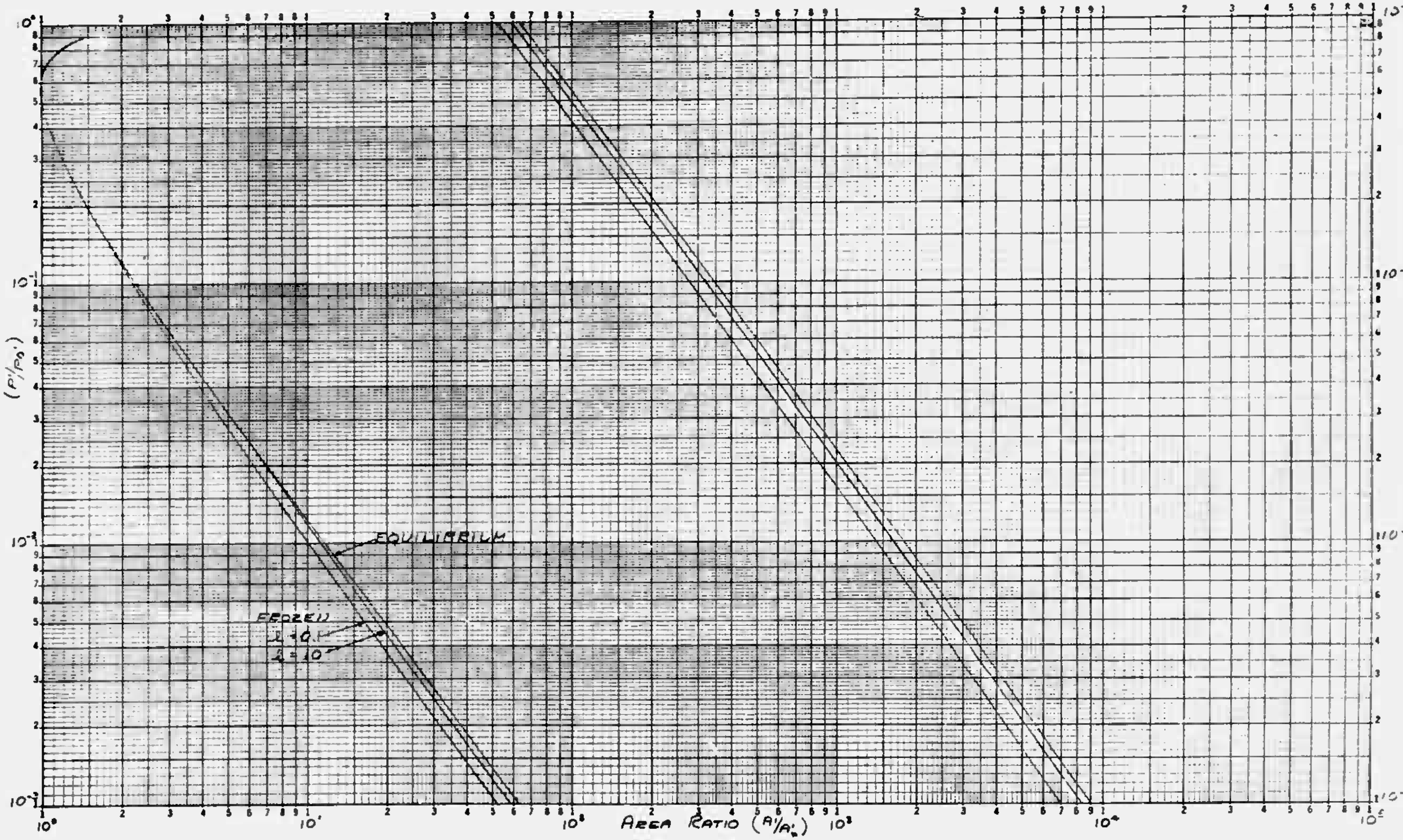


FIGURE NO. 26b HYPERBOLIC NOZZLE $T_c' = 5000°K$ $P_0' = 200$ ATM

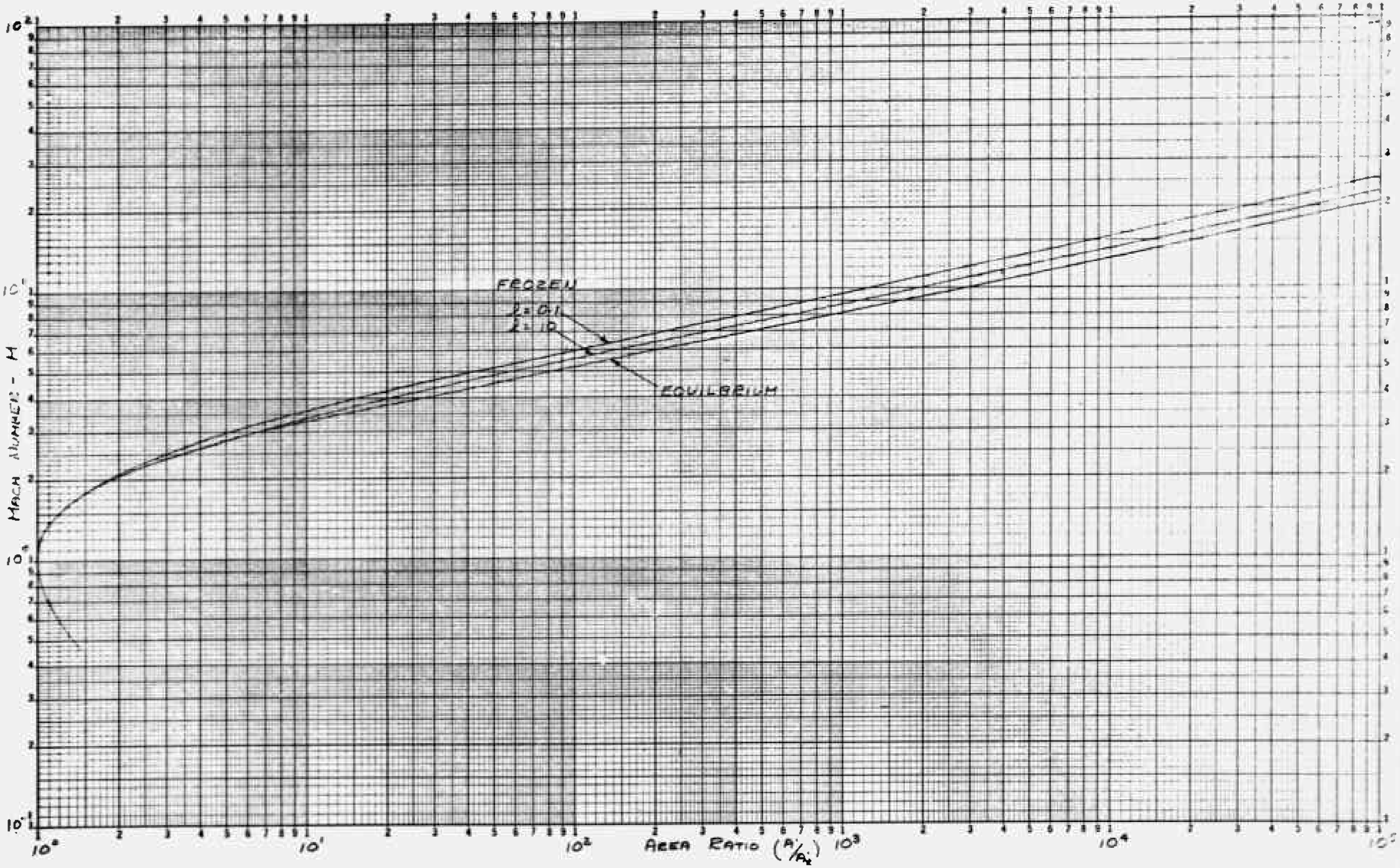


FIGURE NO. 2[illegible] [illegible]ERBOLIC NOZZLE $T_c = 5000°K$ $P_c = 300$ ATM

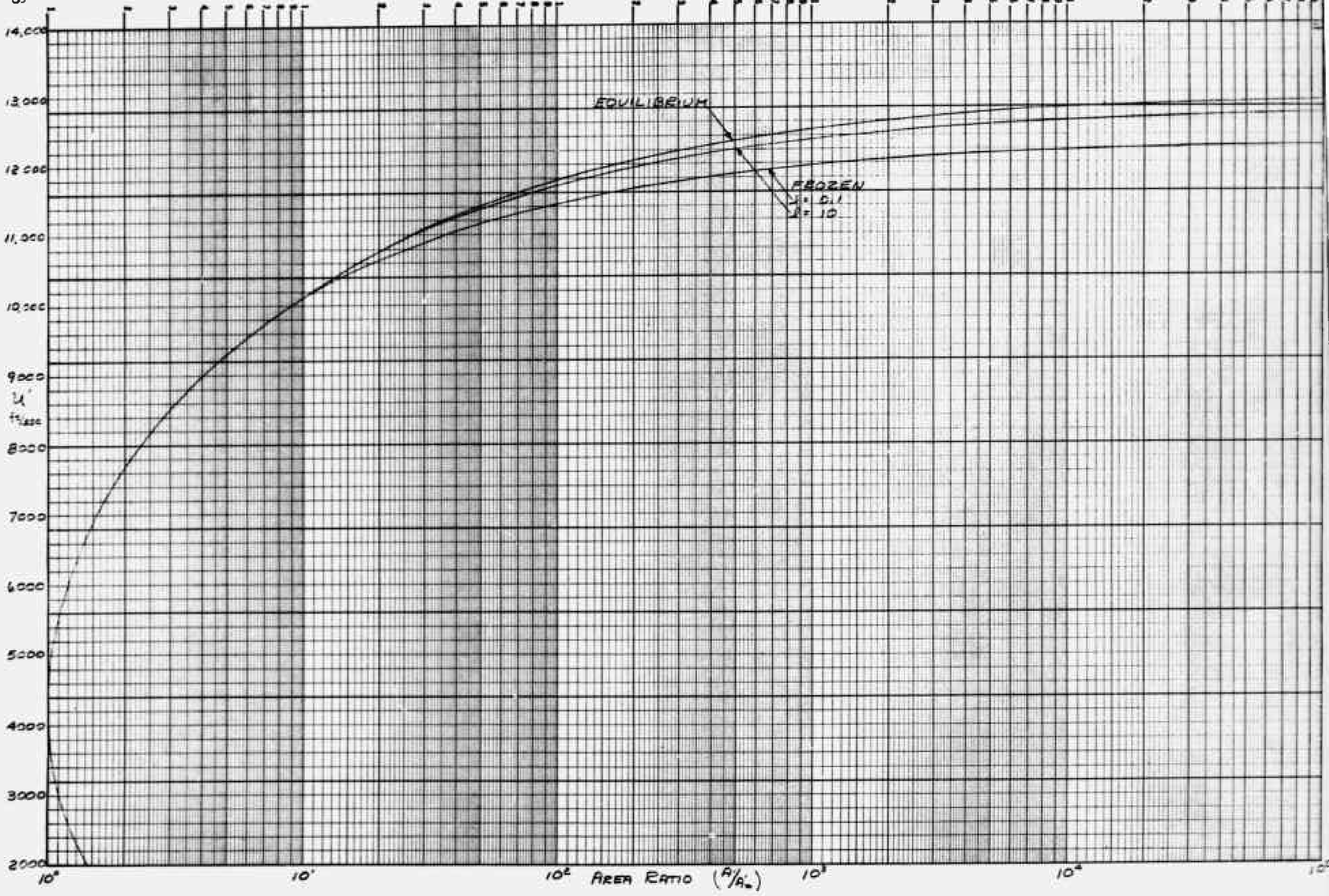


FIGURE NO. 2[illegible] HYPERBOLIC NOZZLE $T_0' = 5000°K$ $P_0' = 200 ATM$

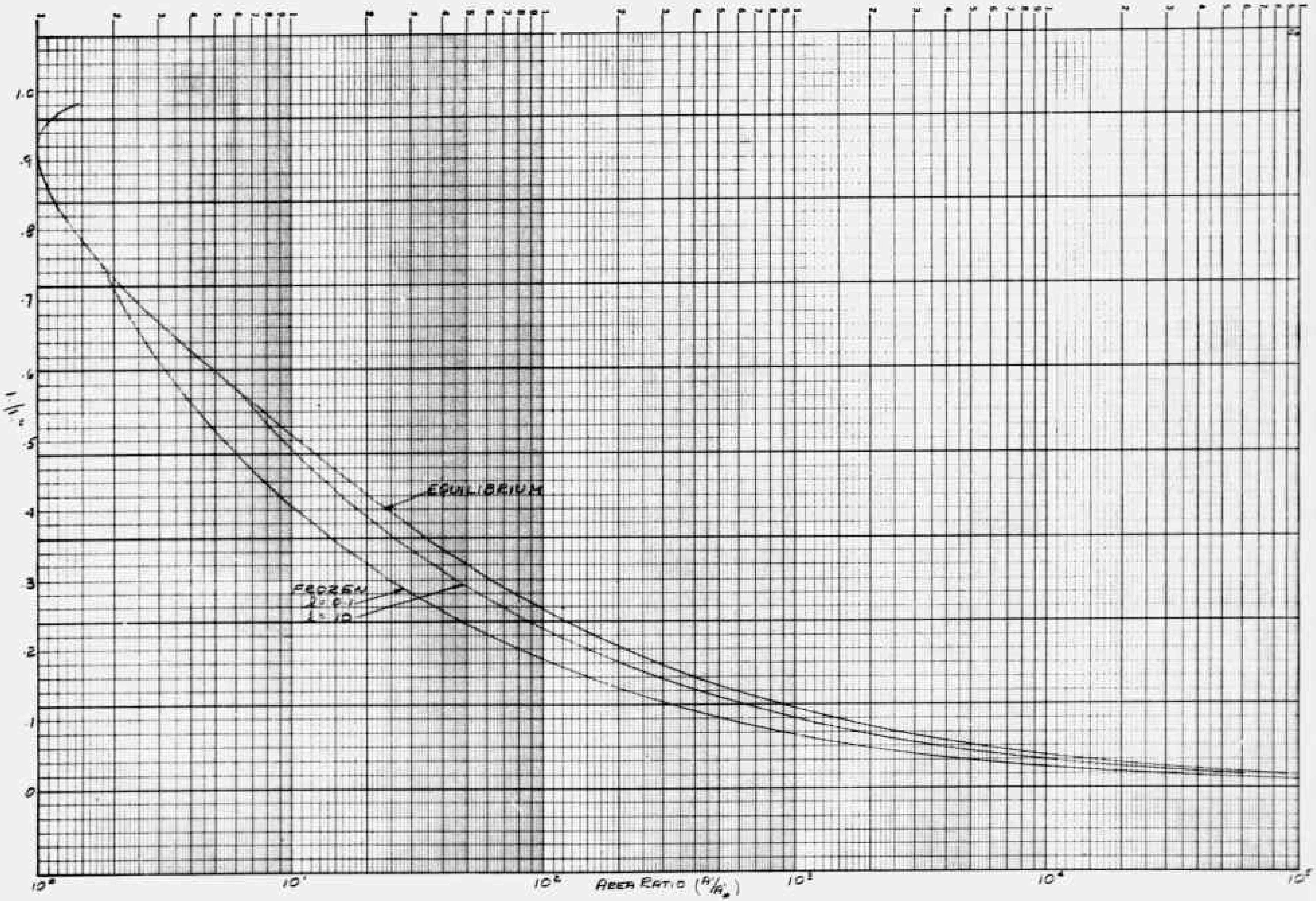


FIGURE NO 262 HYPERBOLIC NOZZLE $T_c' = 5000°K$ $P_c' = 200$ ATM

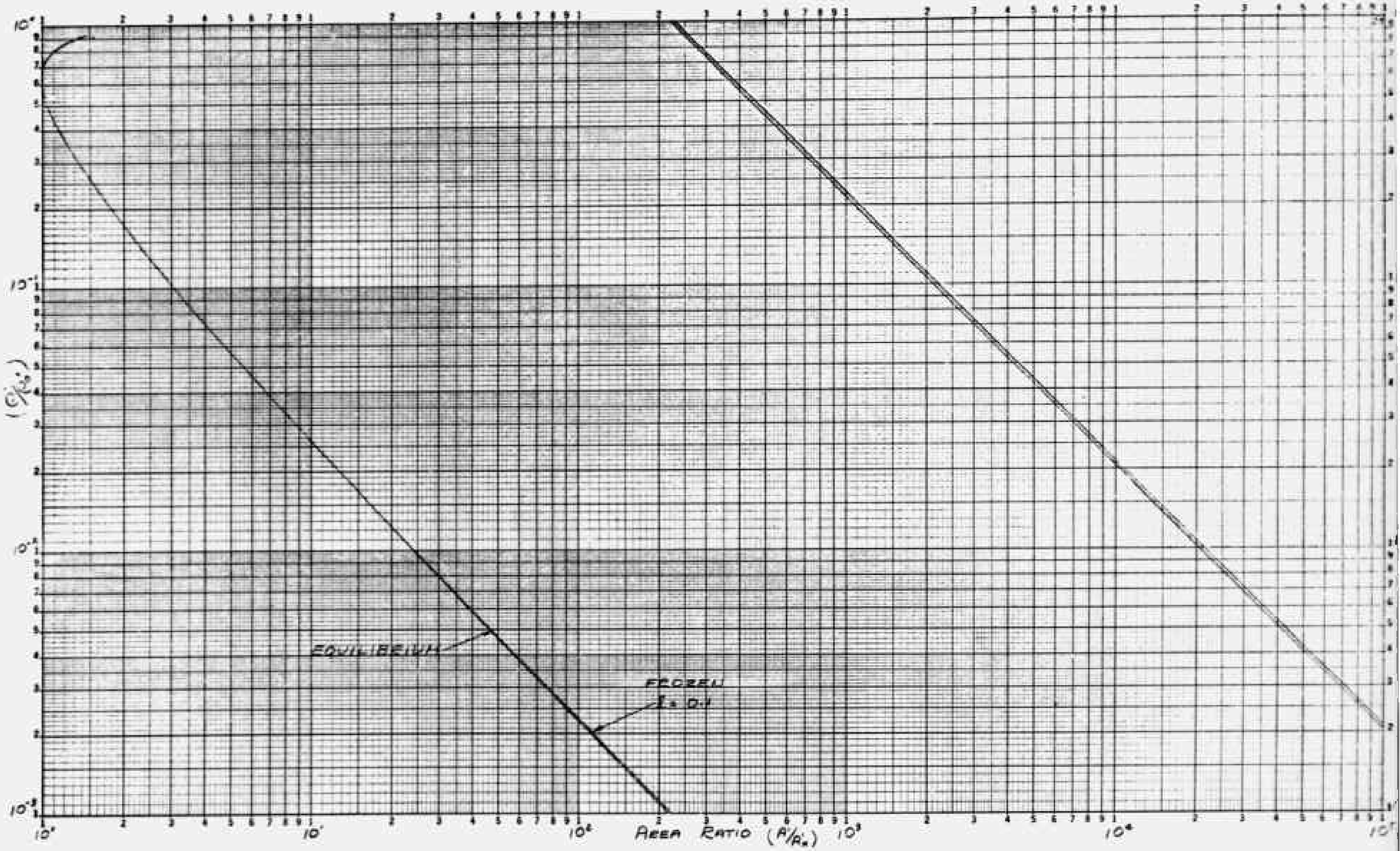


FIGURE NO. 27a HYPERBOLIC NOZZLE $T_0' = 5000\ ^\circ K$ $P_0' = 300$ ATM

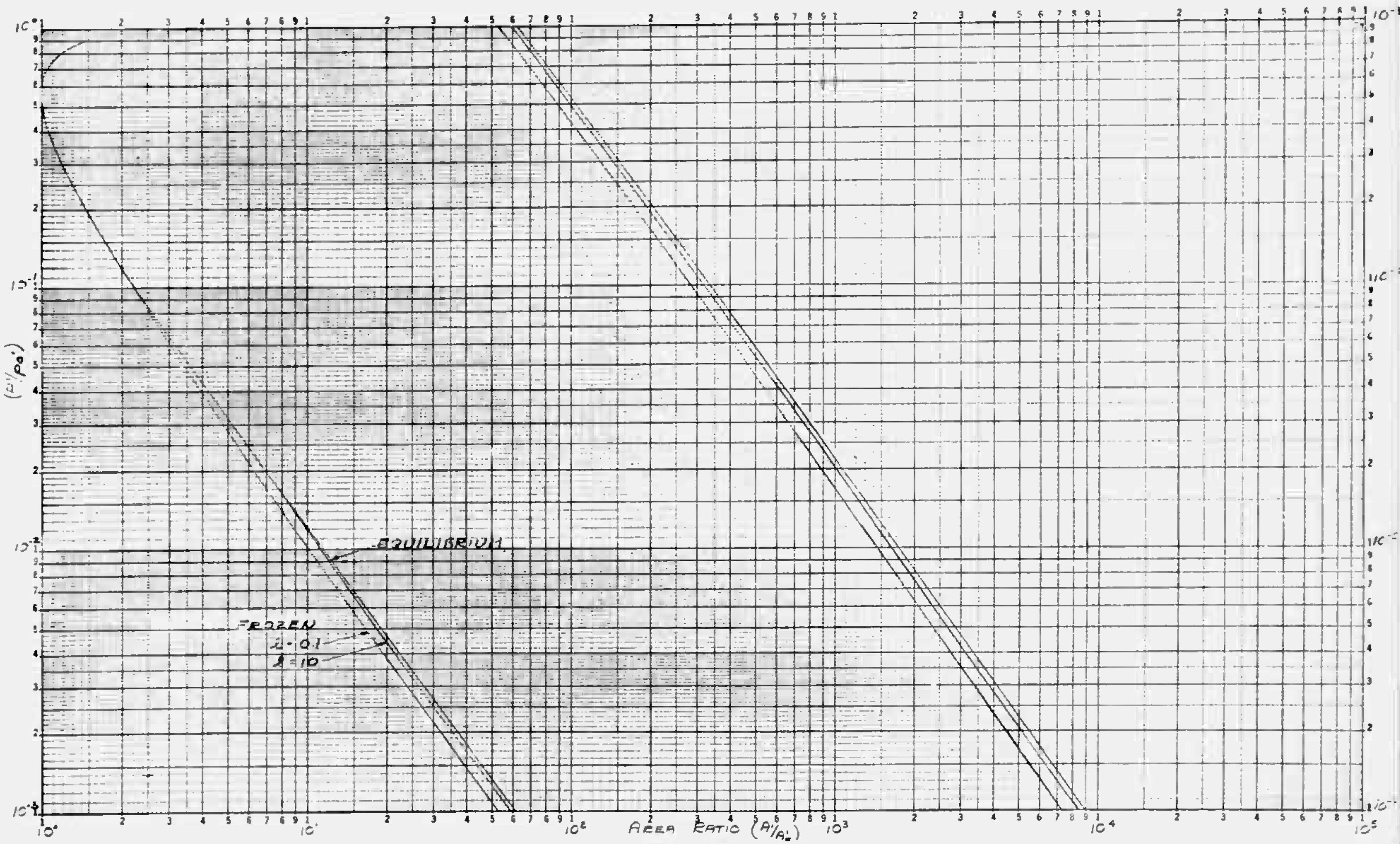


FIGURE NO. 27b HYPERBOLIC NOZZLE $T_0' = 5000°K$ $P_0' = 300$ ATM

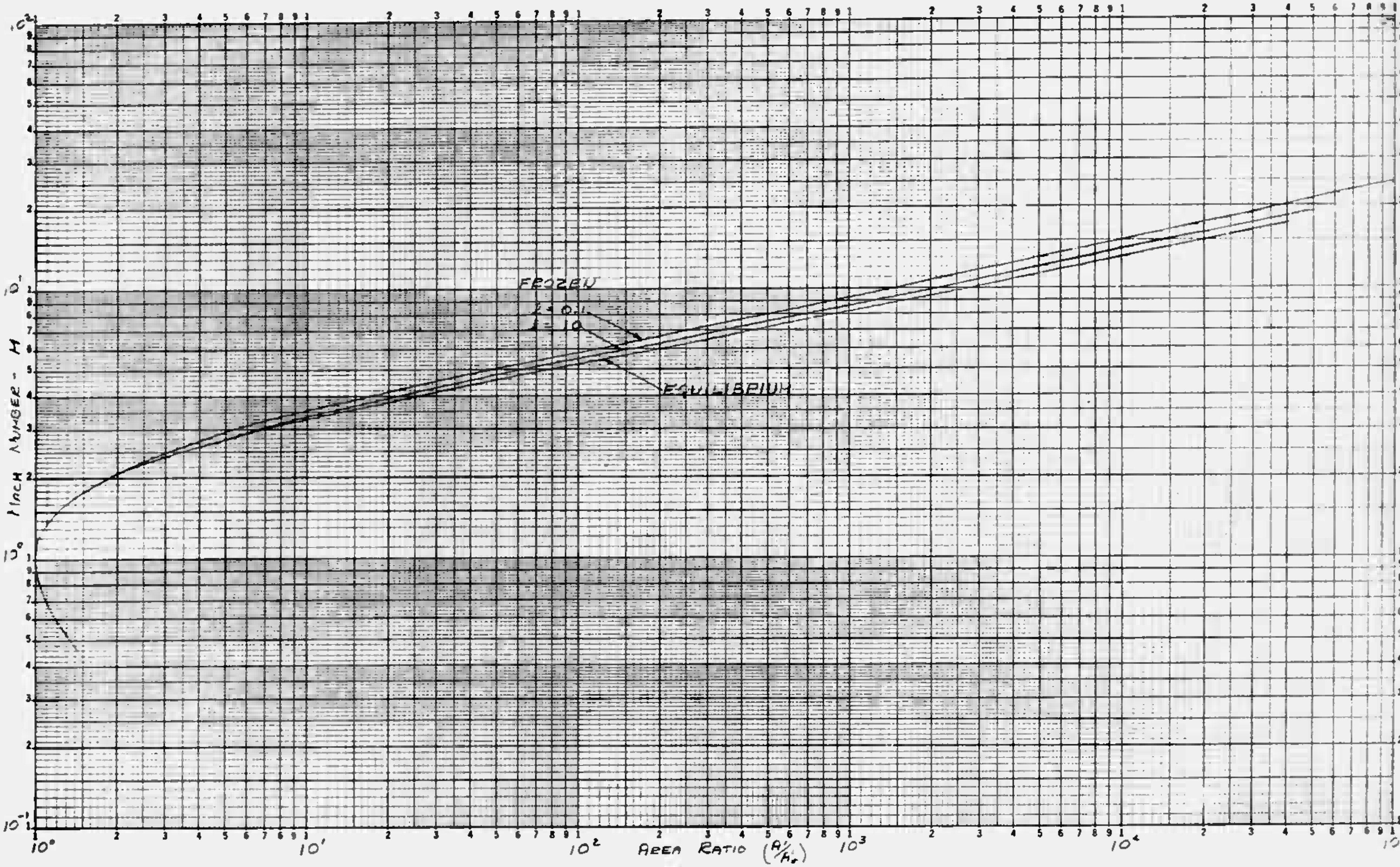


FIGURE NO. 27c HYPERBOLIC NOZZLE $T_o' = 5000°K$ $P_o' = 300$ ATM

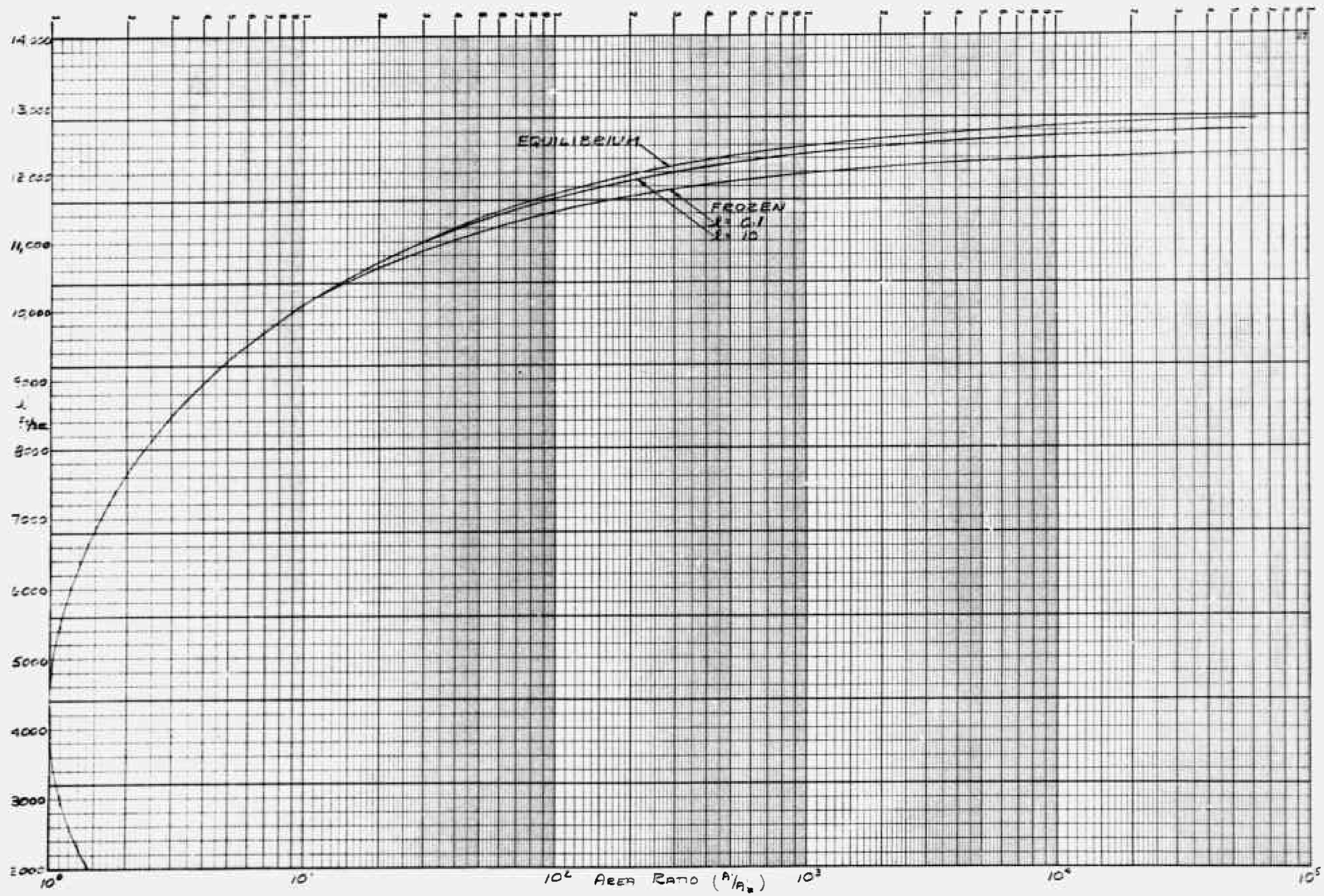


FIGURE NO. 27d HYPERBOLIC NOZZLE $T_0' = 5000°K$ $P_0' = 300$ ATM

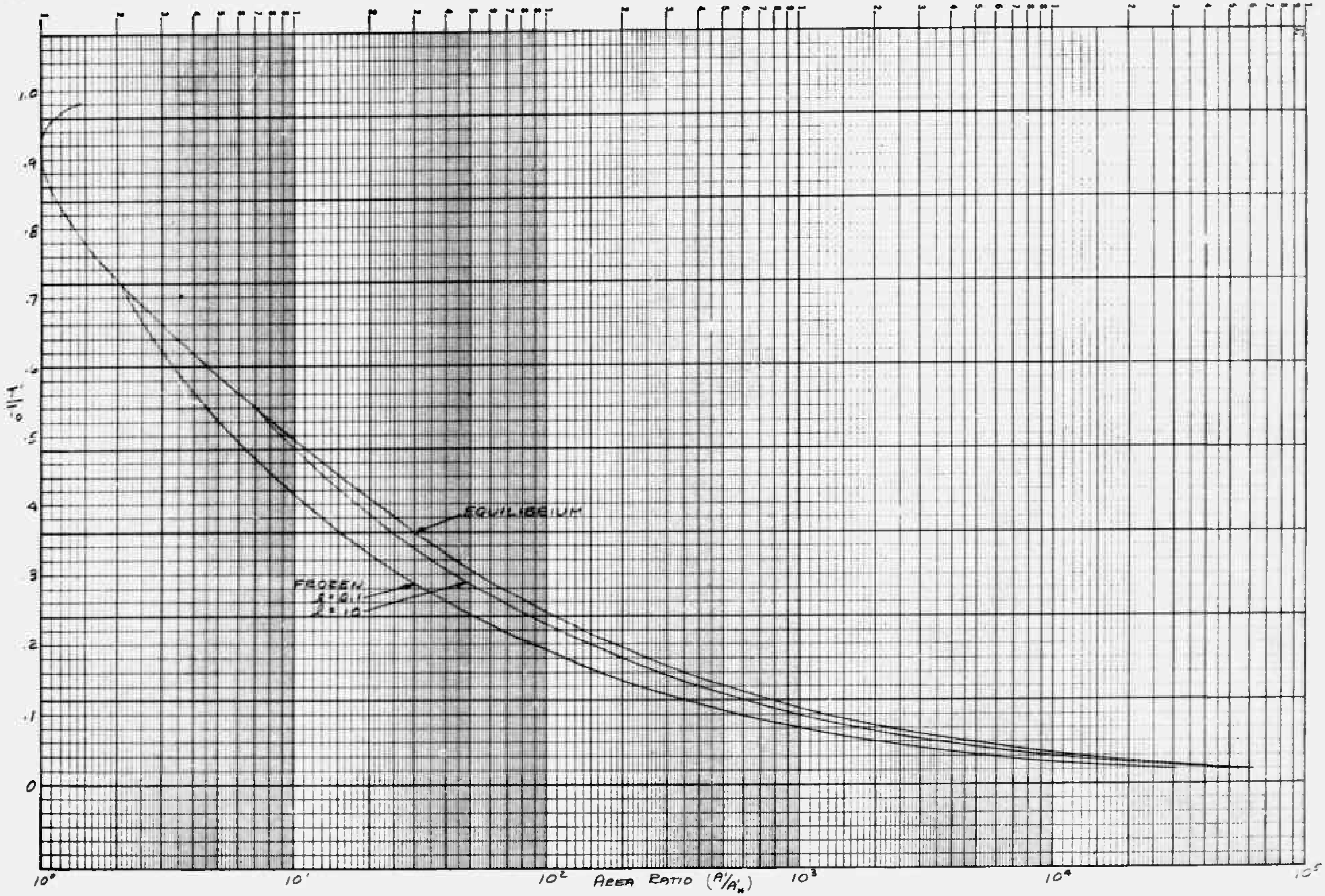


FIGURE NO. 27e HYPERBOLIC NOZZLE $T'_o = 5000°K$ $P'_o = 300$ ATM

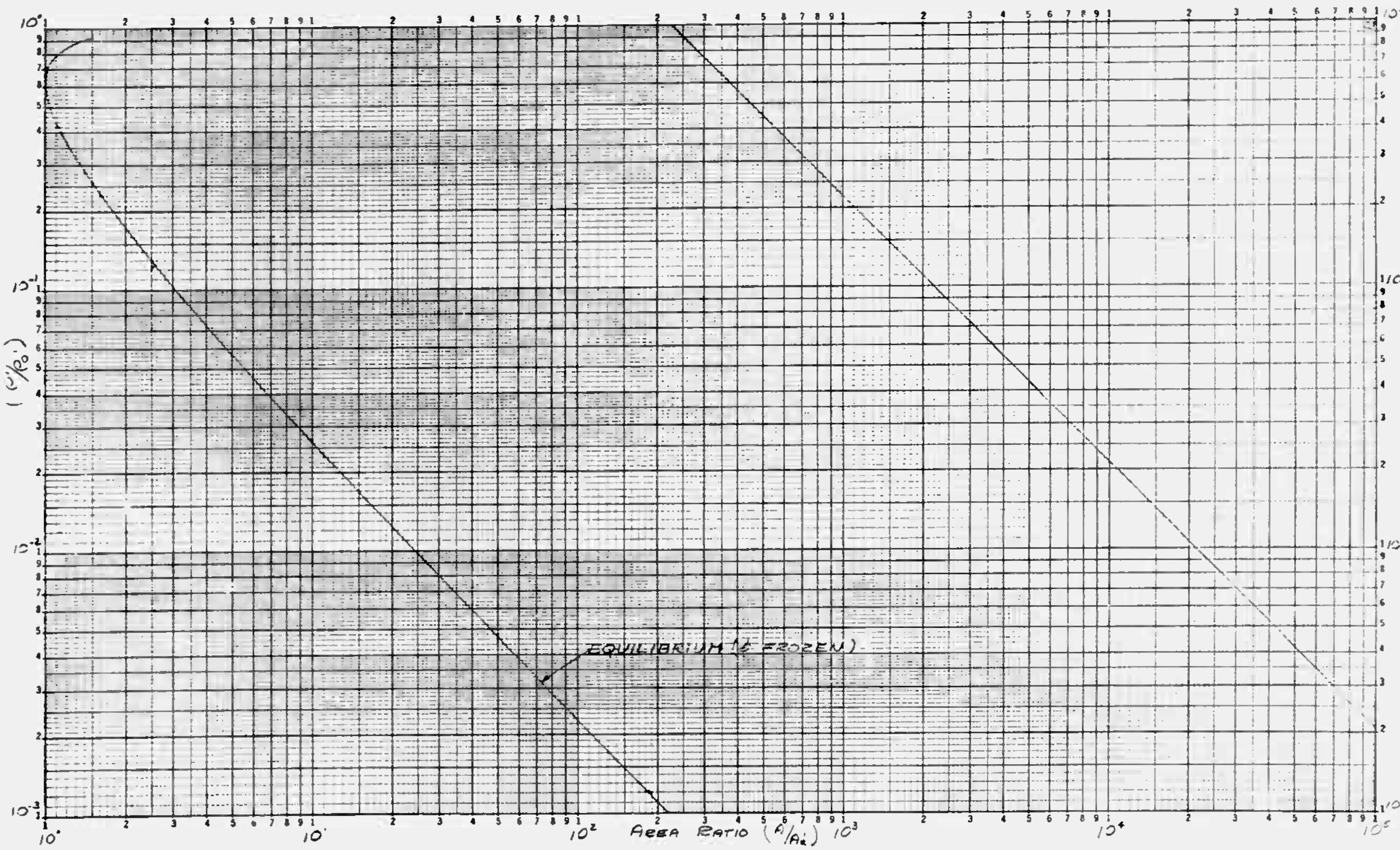


FIGURE NO. 28a HYPERBOLIC NOZZLE $T_0' = 5000°K$ $P_0' = 1000$ ATM

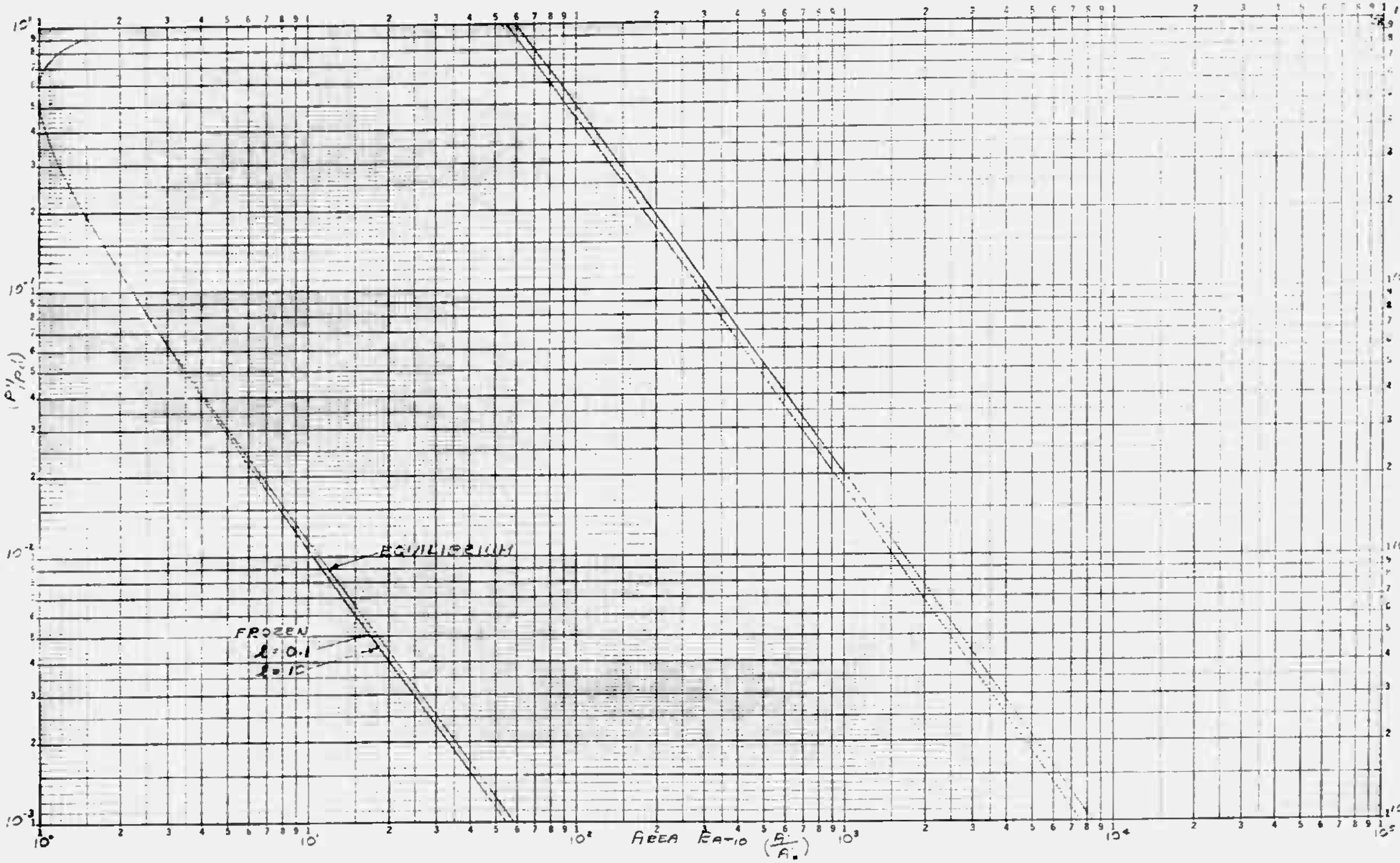


FIGURE NO. 28b HYPERBOLIC NOZZLE $T_c' = 5000\,°K$ $p_c' = 1000$ ATM

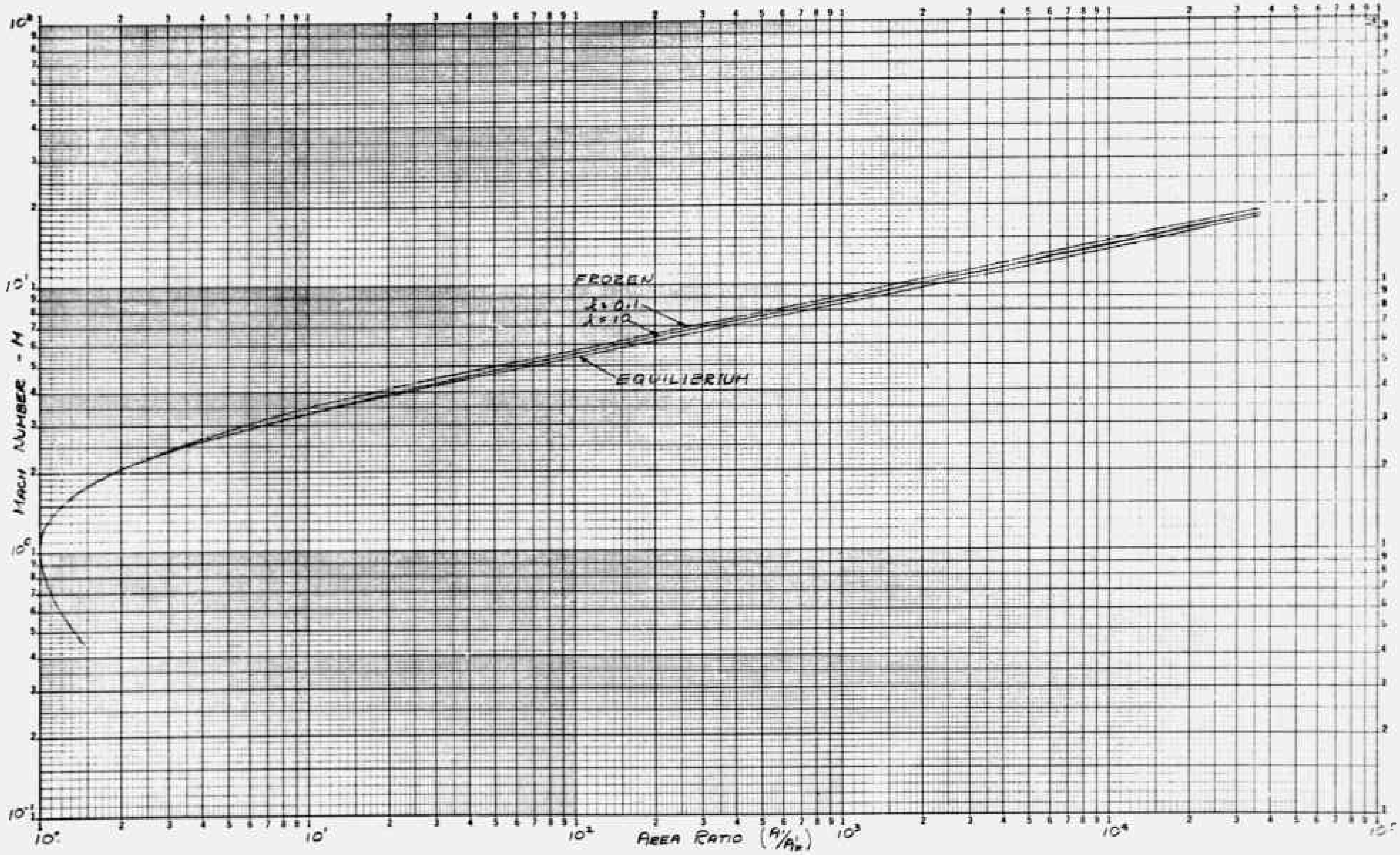


FIGURE NO. 28c HYPERBOLIC NOZZLE $T_0' = 5000°K$ $P_0' = 1000$ ATM

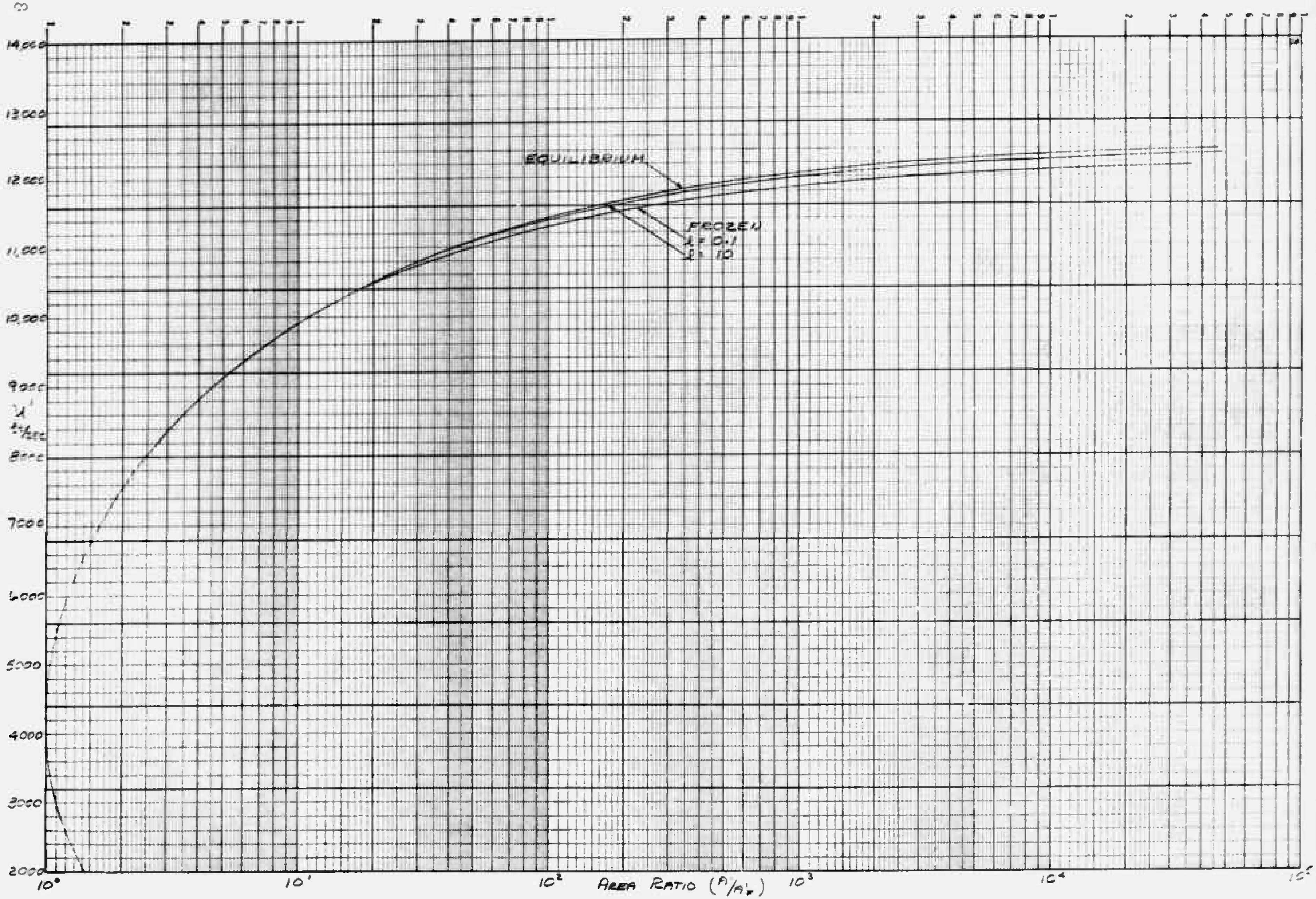


FIGURE NO. 28d HYPERBOLIC NOZZLE $T'_0 = 5000°K$ $P'_c = 1000$ ATM

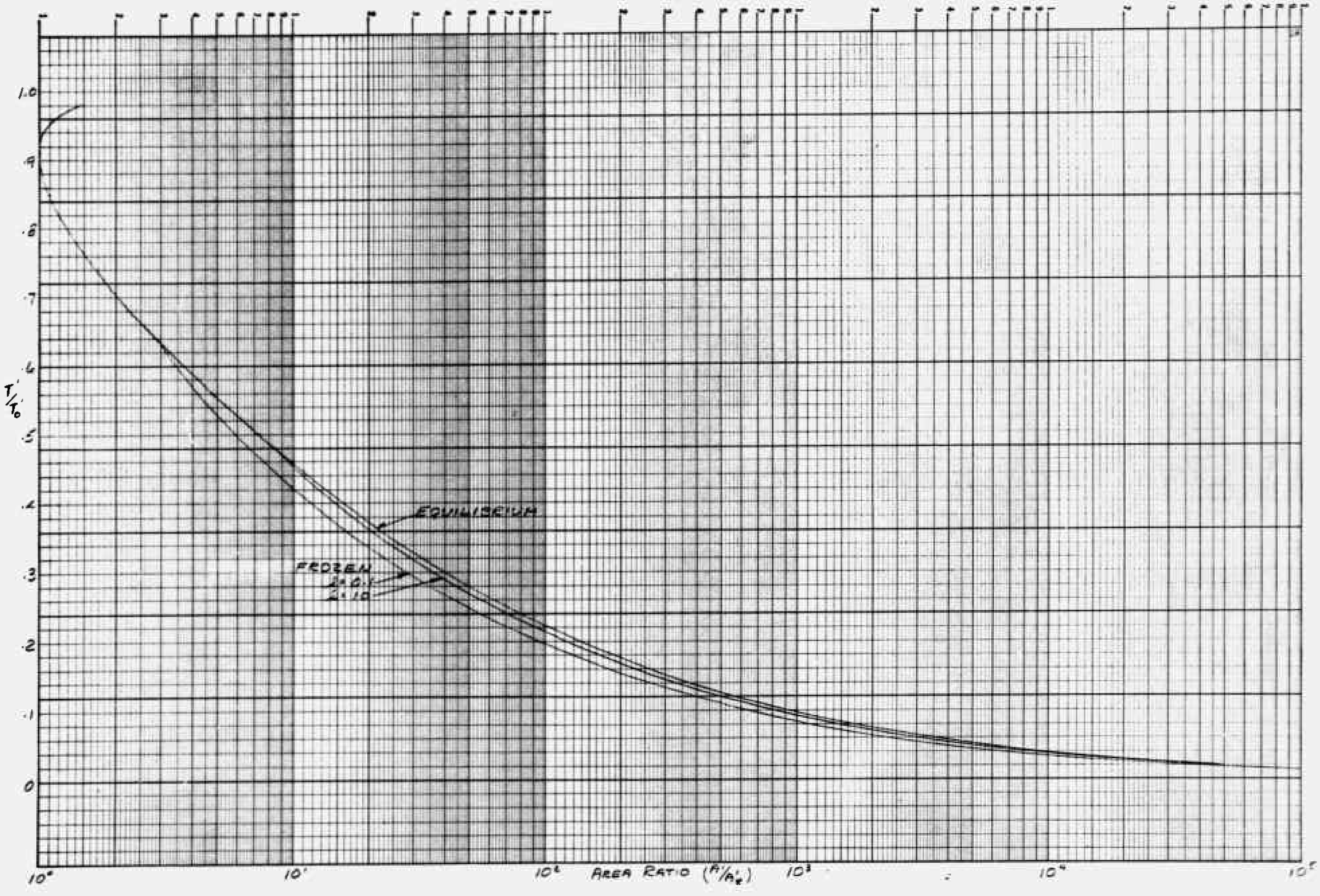


FIGURE NO. 28e HYPERBOLIC NOZZLE $T'_0 = 5000°K$ $P'_0 = 1000$ ATM

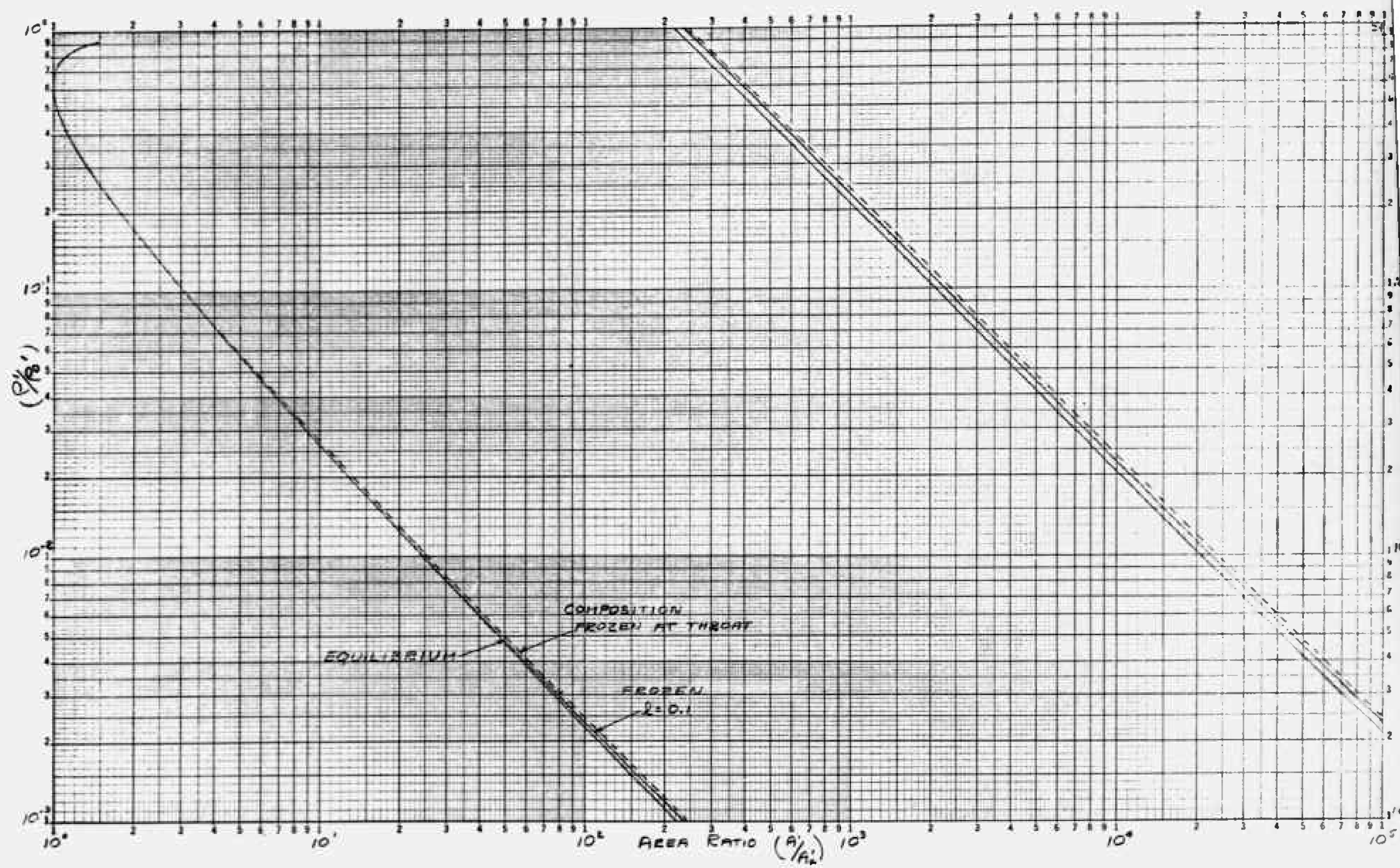


FIGURE NO. 29a HYPERBOLIC NOZZLE $T_0' = 6000°K$ $P_0' = 100$ ATM

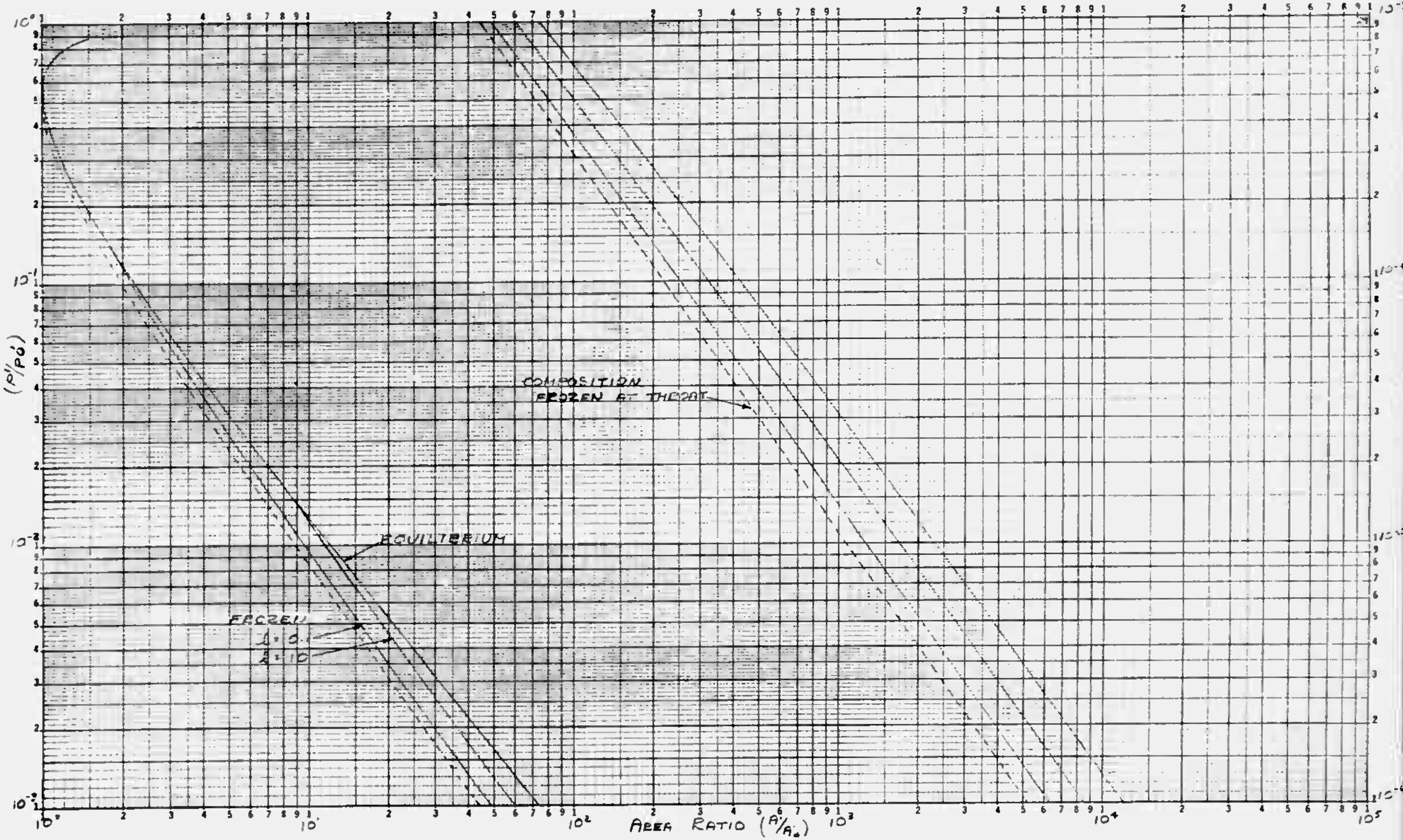


FIGURE NO. 29b HYPERBOLIC NOZZLE $T'_c = 6000°K$ $P'_c = 100$ ATM

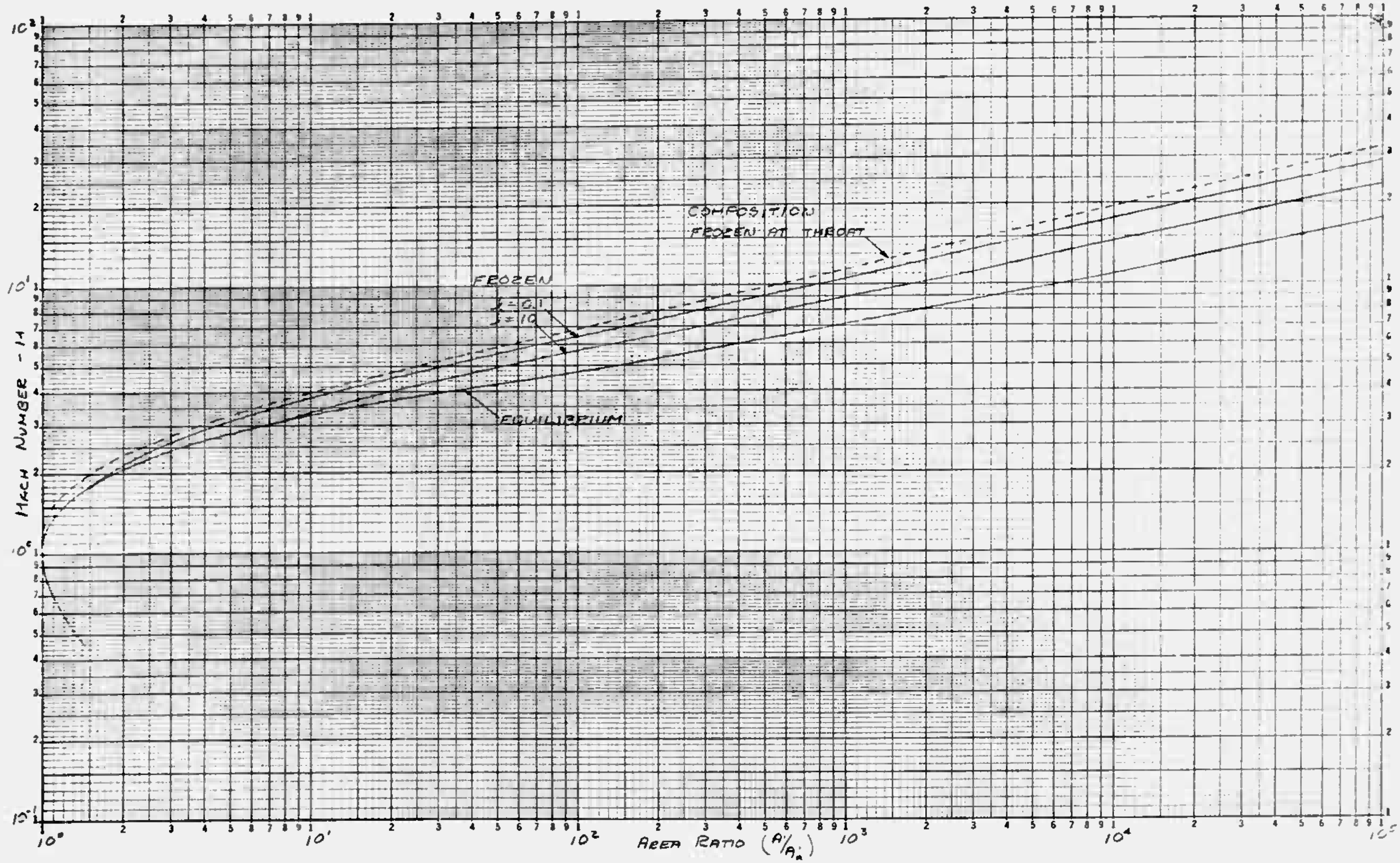


FIGURE NO. 29c HYPERBOLIC NOZZLE $T'_o = 6000°K$ $P'_o = 100$ ATM

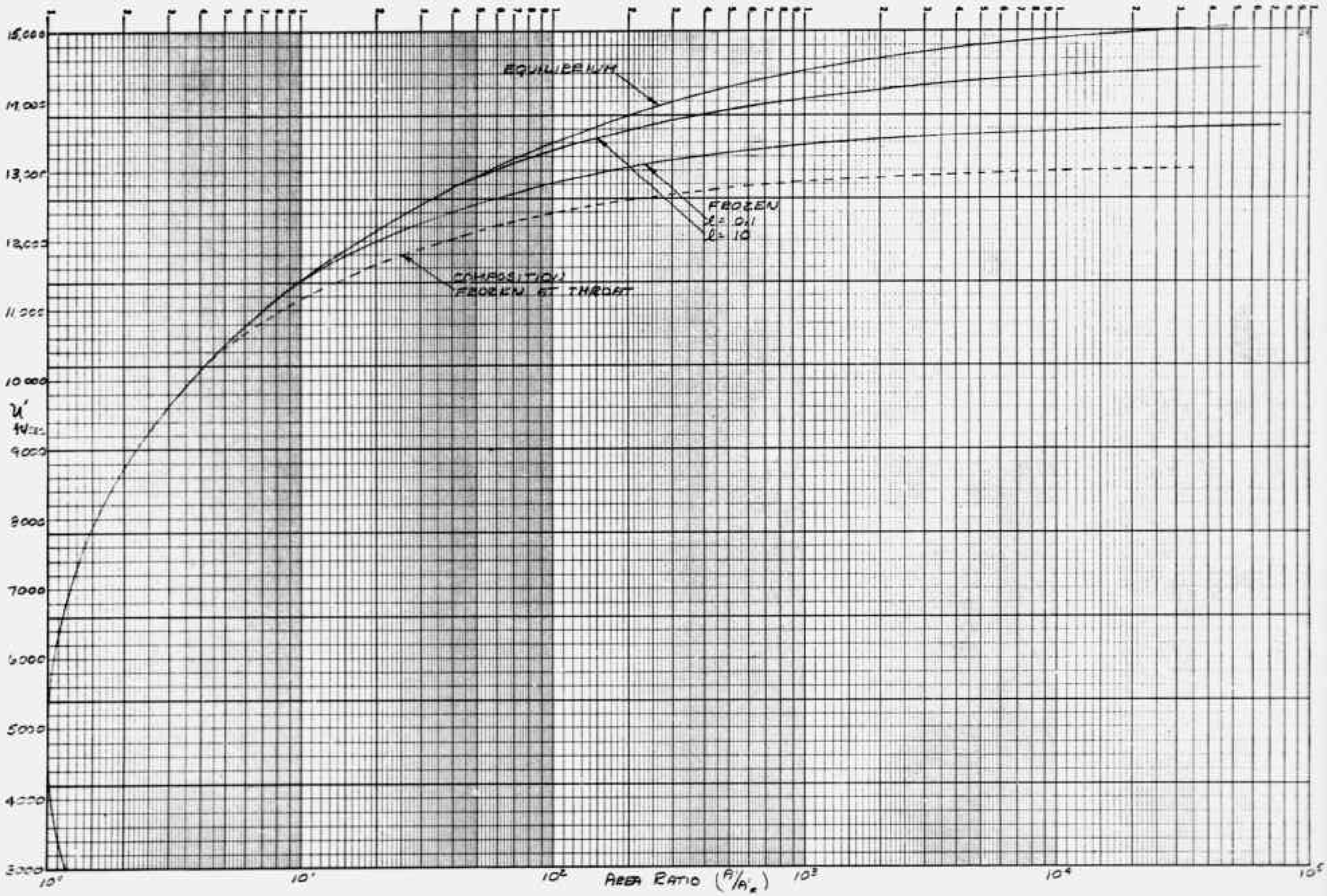


FIGURE NO 29d HYPERBOLIC NOZZLE $T_0' = 6000°K$ $P_0' = 100$ ATM

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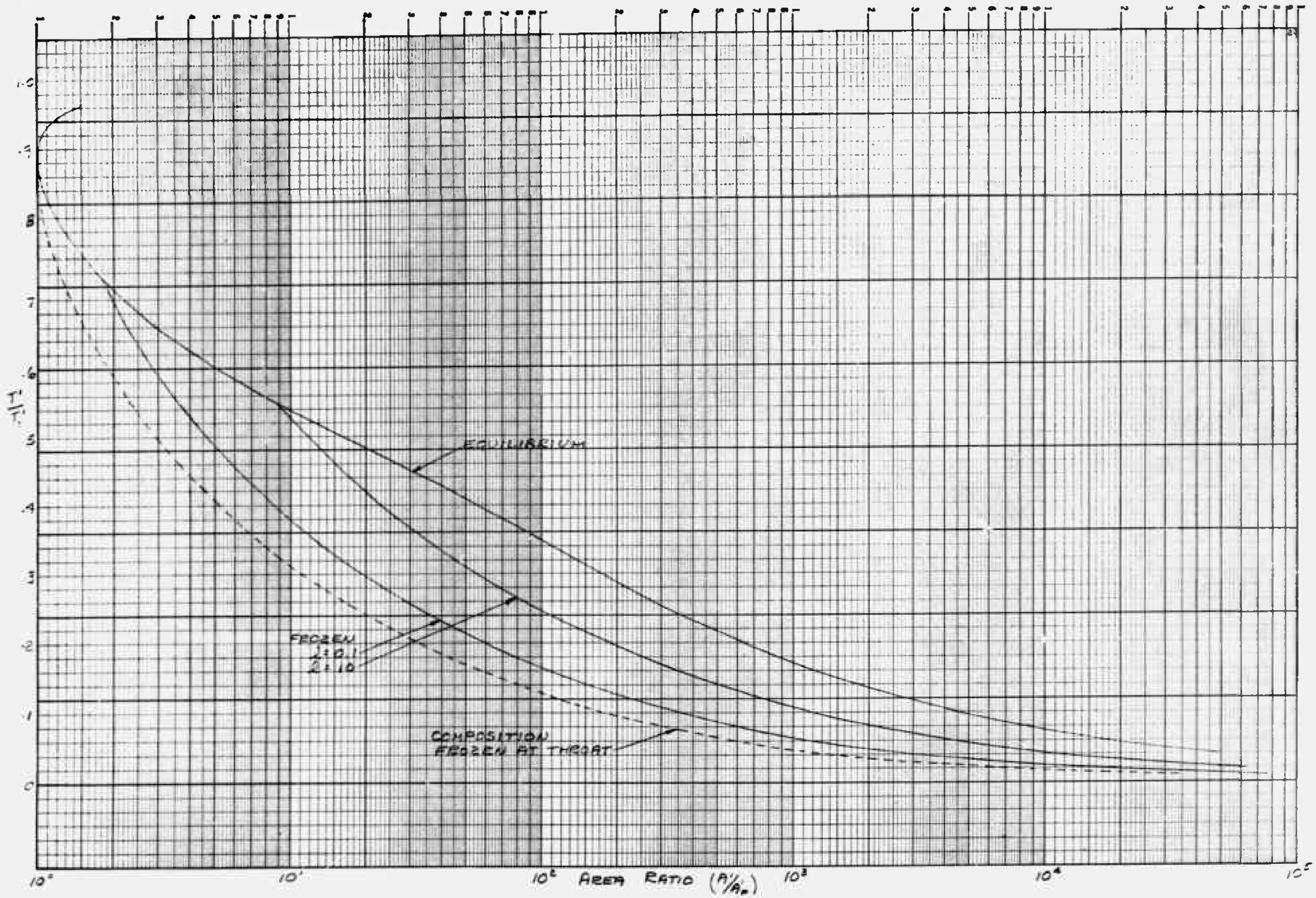

FIGURE NO 29e HYPERBOLIC NOZZLE $T_0' = 6000°K$ $P_0' = 100 ATM$

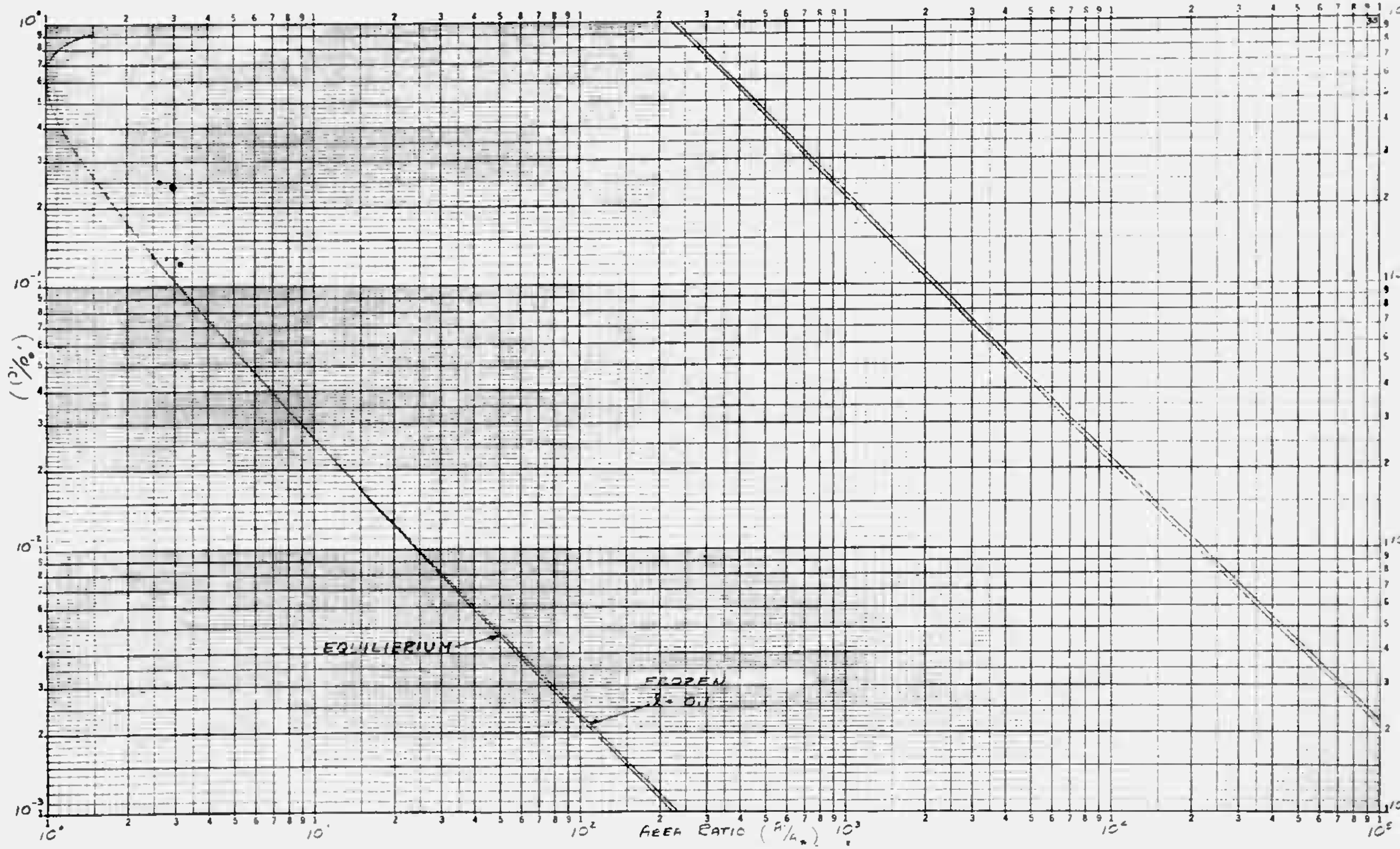

FIGURE NO. 30a HYPERBOLIC NOZZLE $T_0' = 6000°K$ $P_0' = 300$ ATM

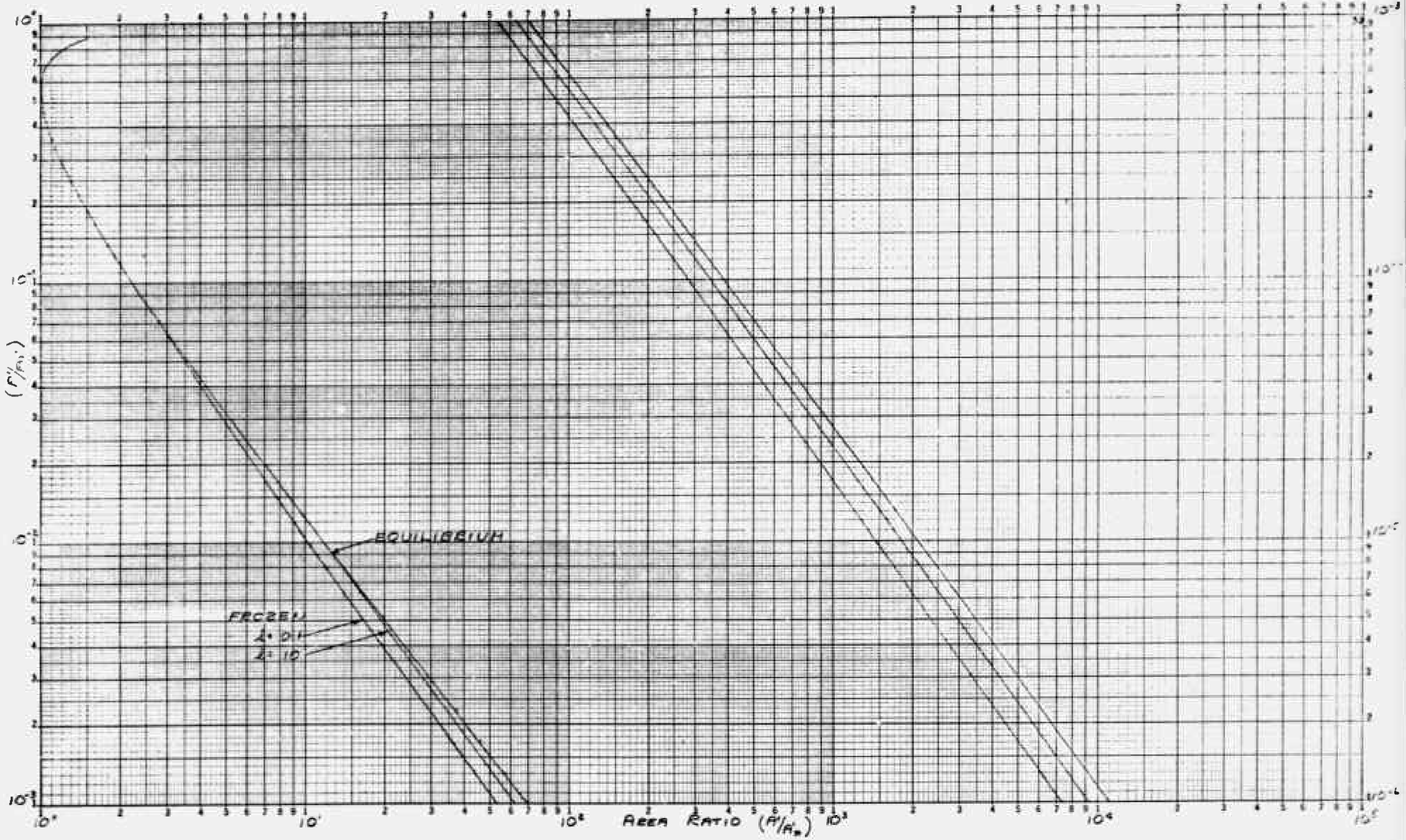

FIGURE NO. 30b HYPERBOLIC NOZZLE $T_0' = 6000°K$ $P_0' = 300 ATM$

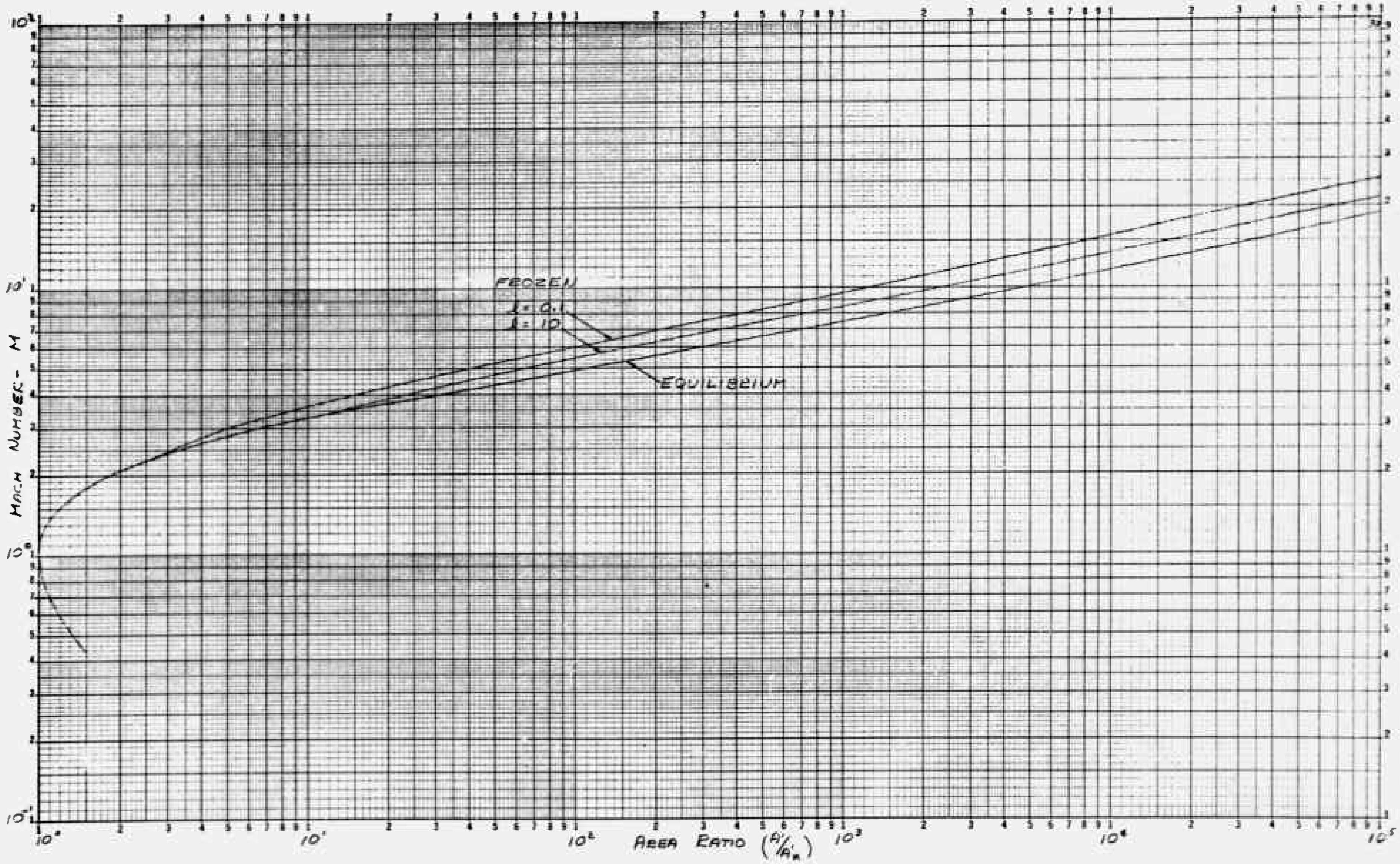

FIGURE NO. 30c HYPERBOLIC NOZZLE $T_o' = 6000\,°K$ $P_o' = 300$ ATM

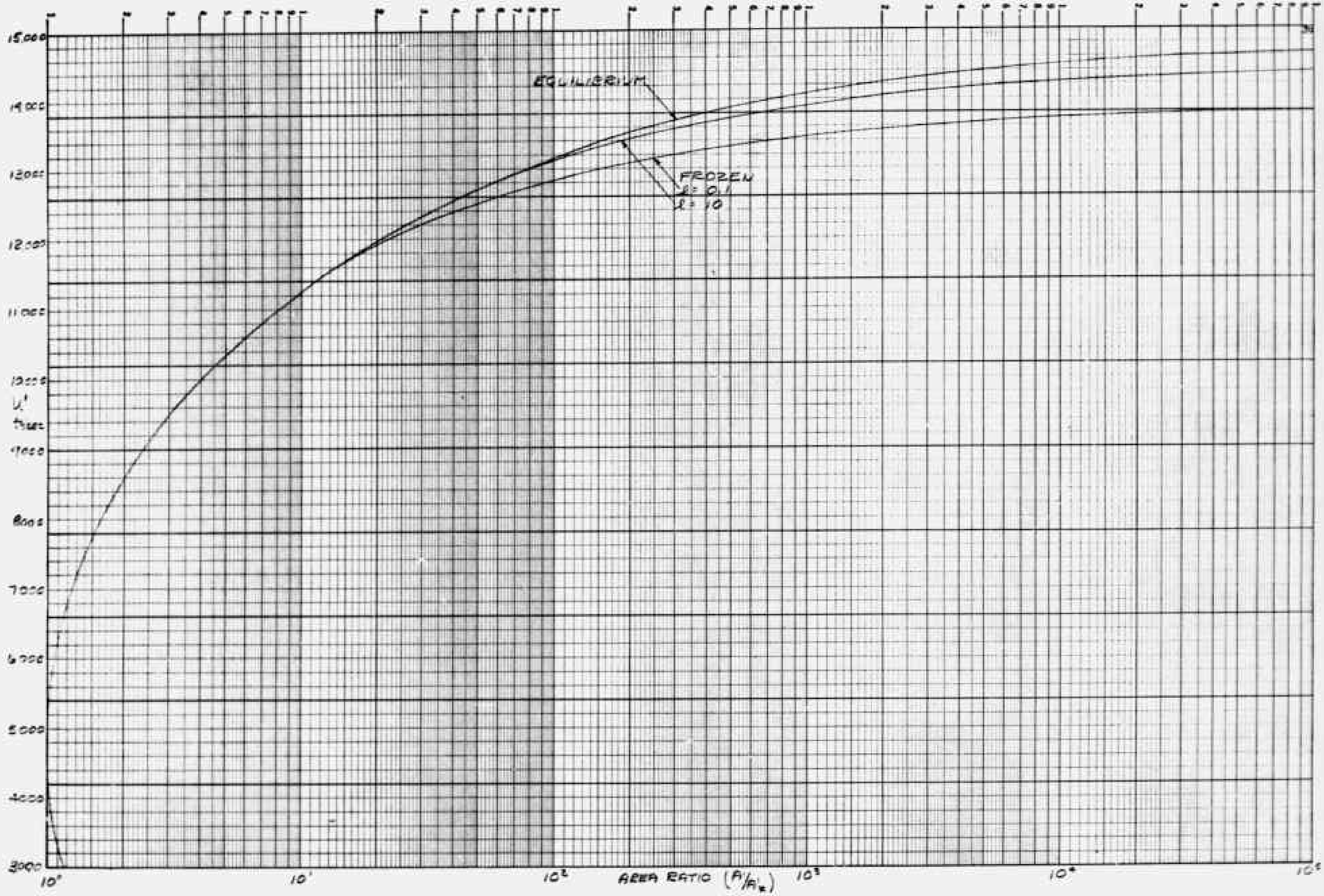

FIGURE NO. 30d HYPERSONIC NOZZLE $T_0' = 6000°K$ $P_0' = 300$ ATM

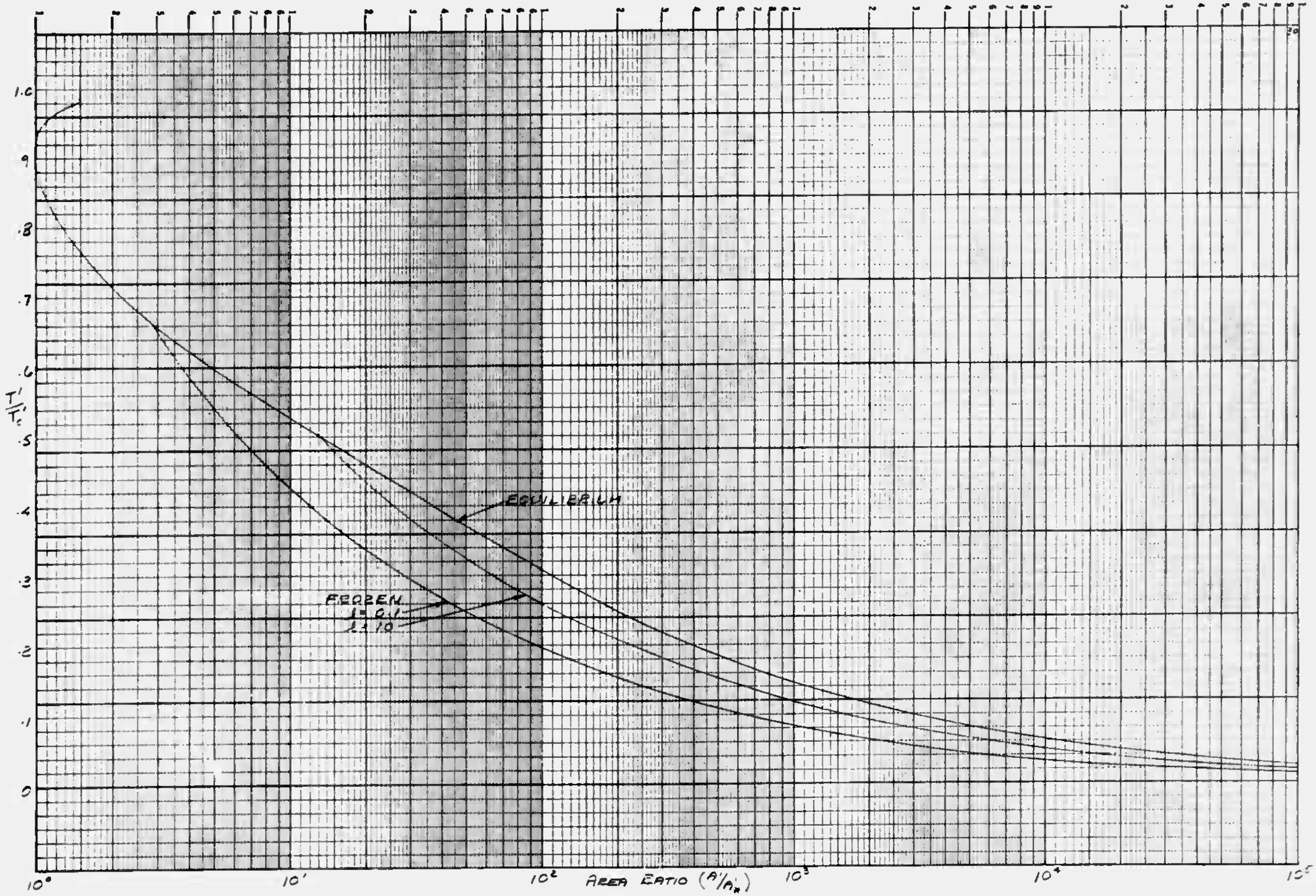

FIGURE NO 30e HYPERBOLIC NOZZLE $T'_0 = 6000°K$ $P'_0 = 300$ ATM

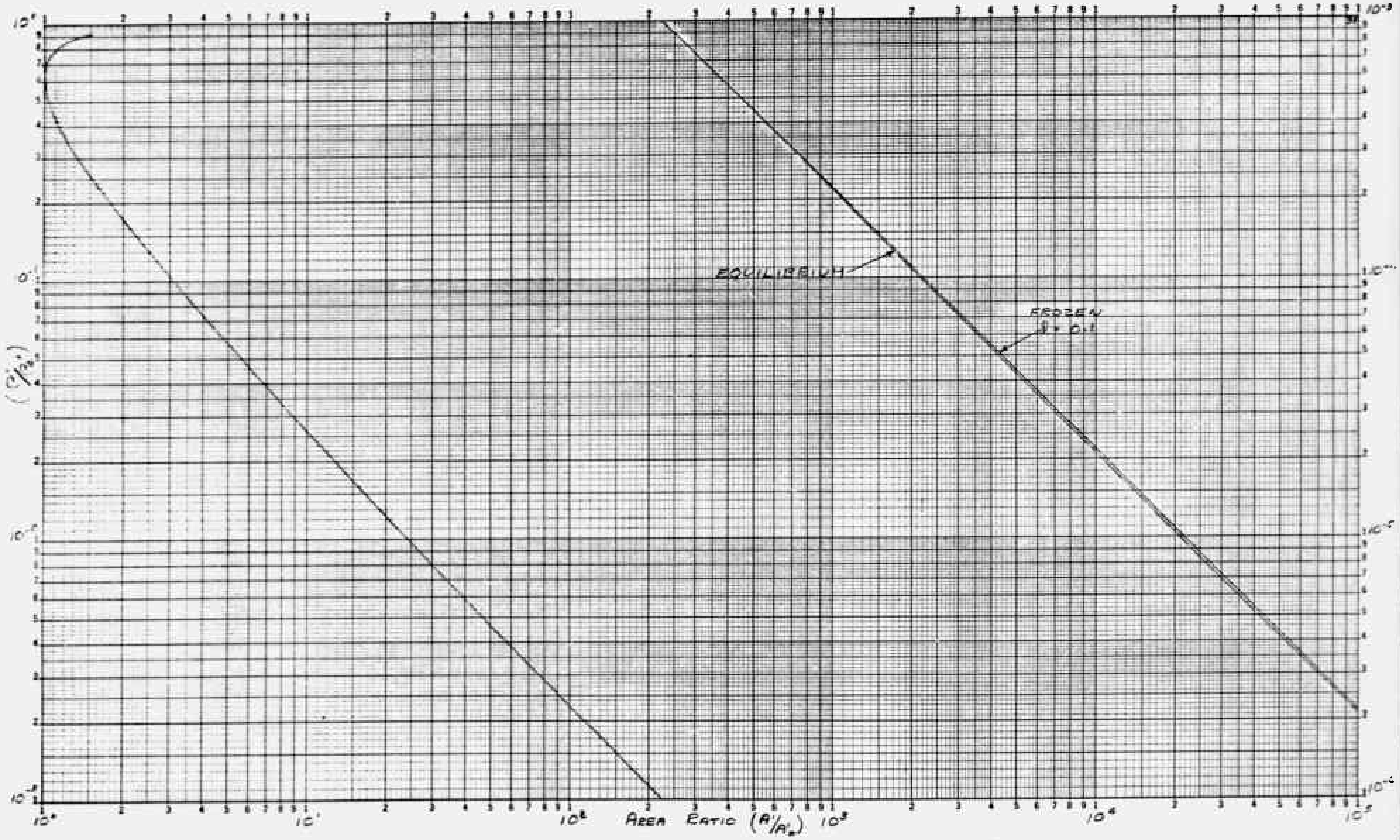

FIGURE NO. 31a HYPERBOLIC NOZZLE $T'_0 = 6000°K$ $P'_0 = 1000$ ATM

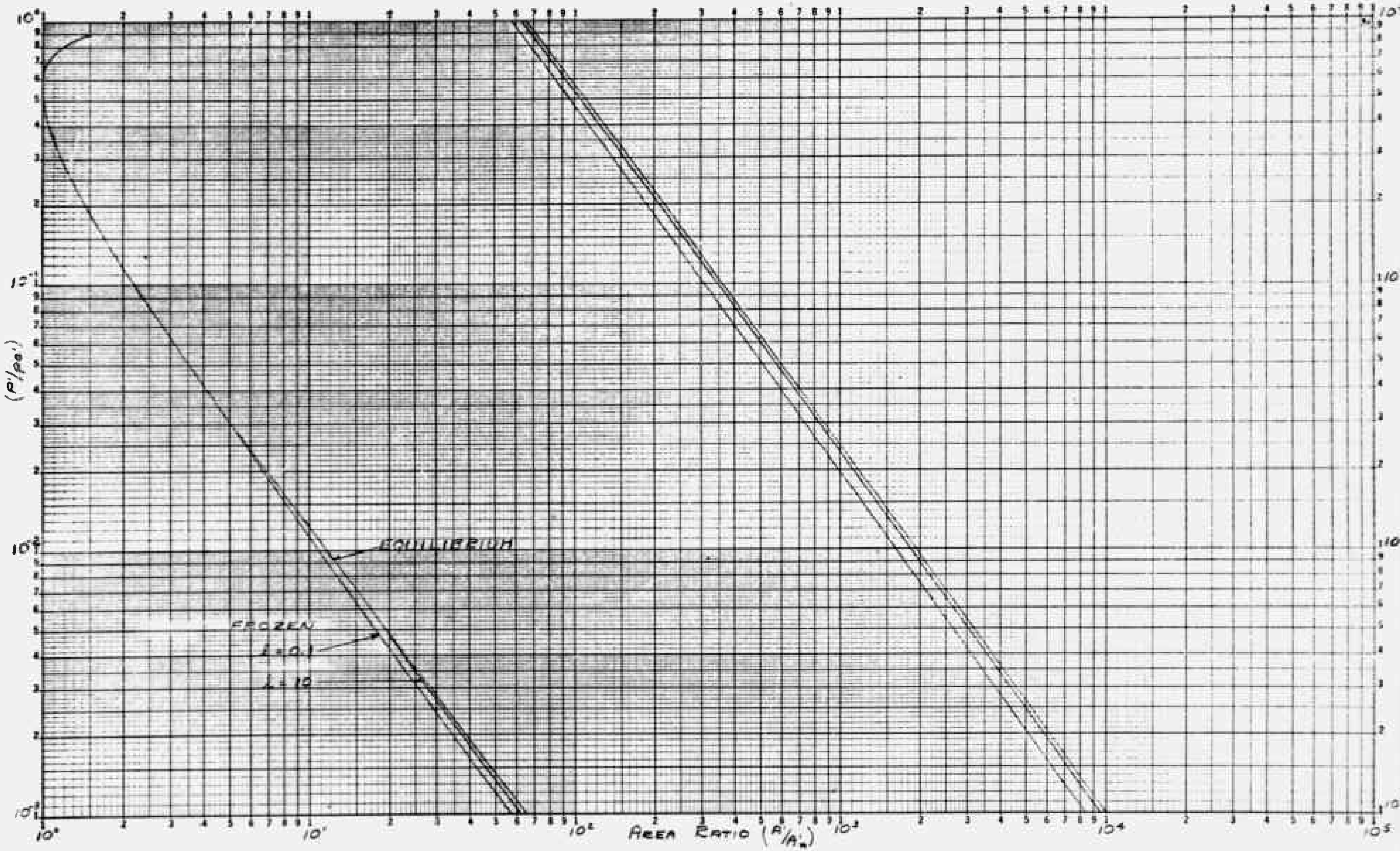

FIGURE NO. 31b HYPERBOLIC NOZZLE $T_0' = 6000°K$ $P_0' = 1000$ ATM

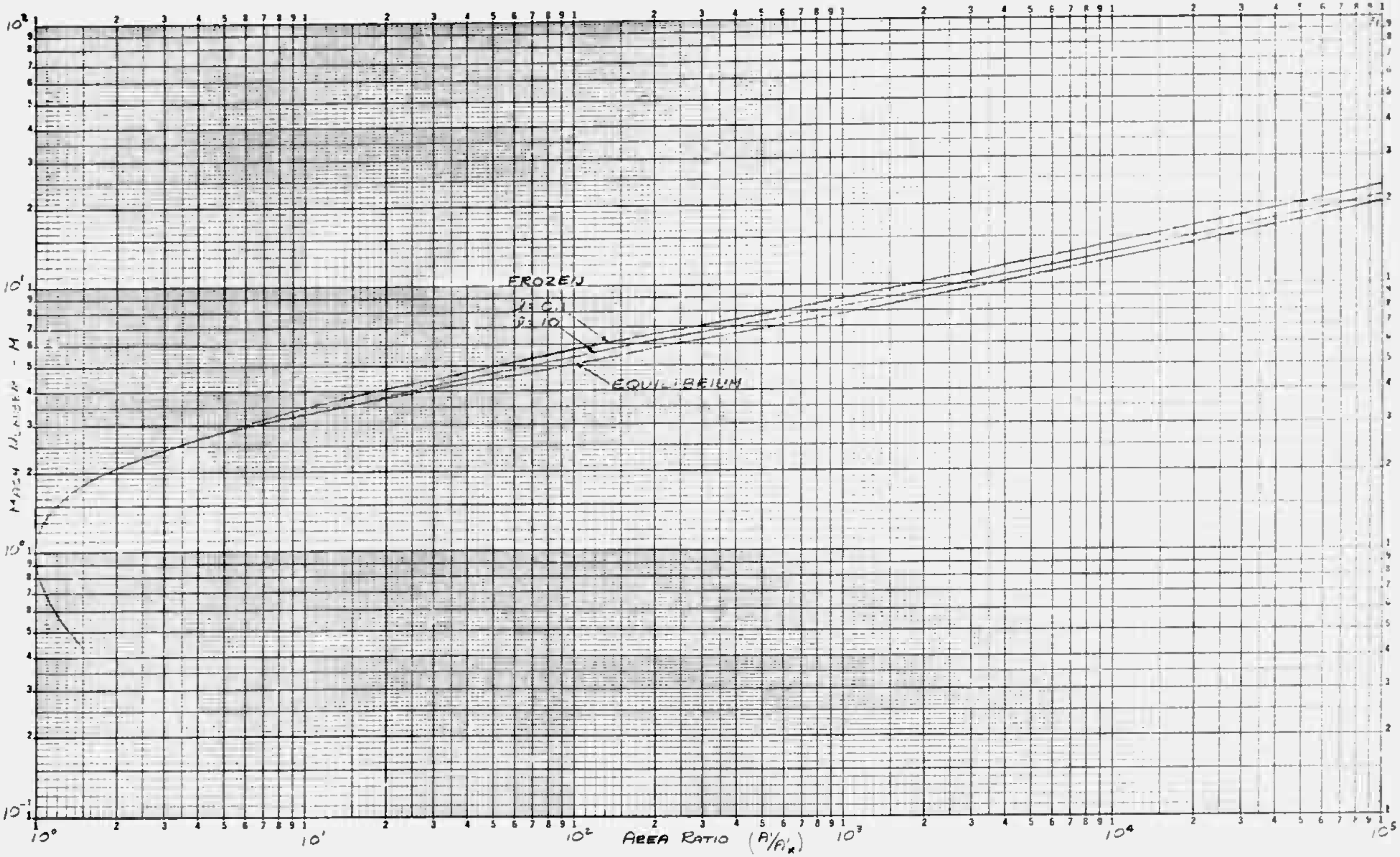

FIGURE NO. 31c HYPERBOLIC NOZZLE $T_o' = 6000\,°K$ $P_o' = 1000$ ATM

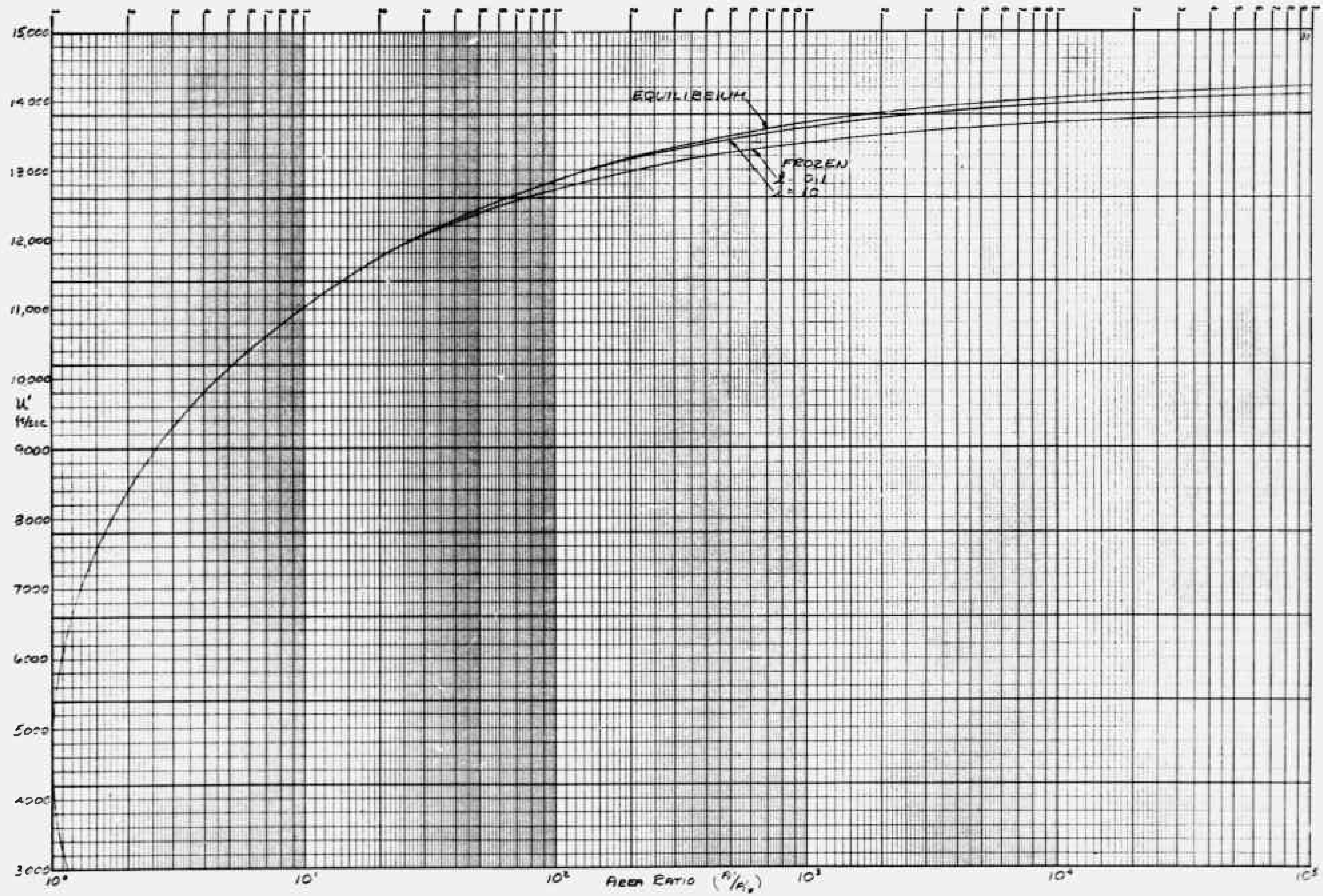

FIGURE NO. 31d HYPERBOLIC NOZZLE $T_0' = 6000°K$ $P_0' = 1000$ ATM

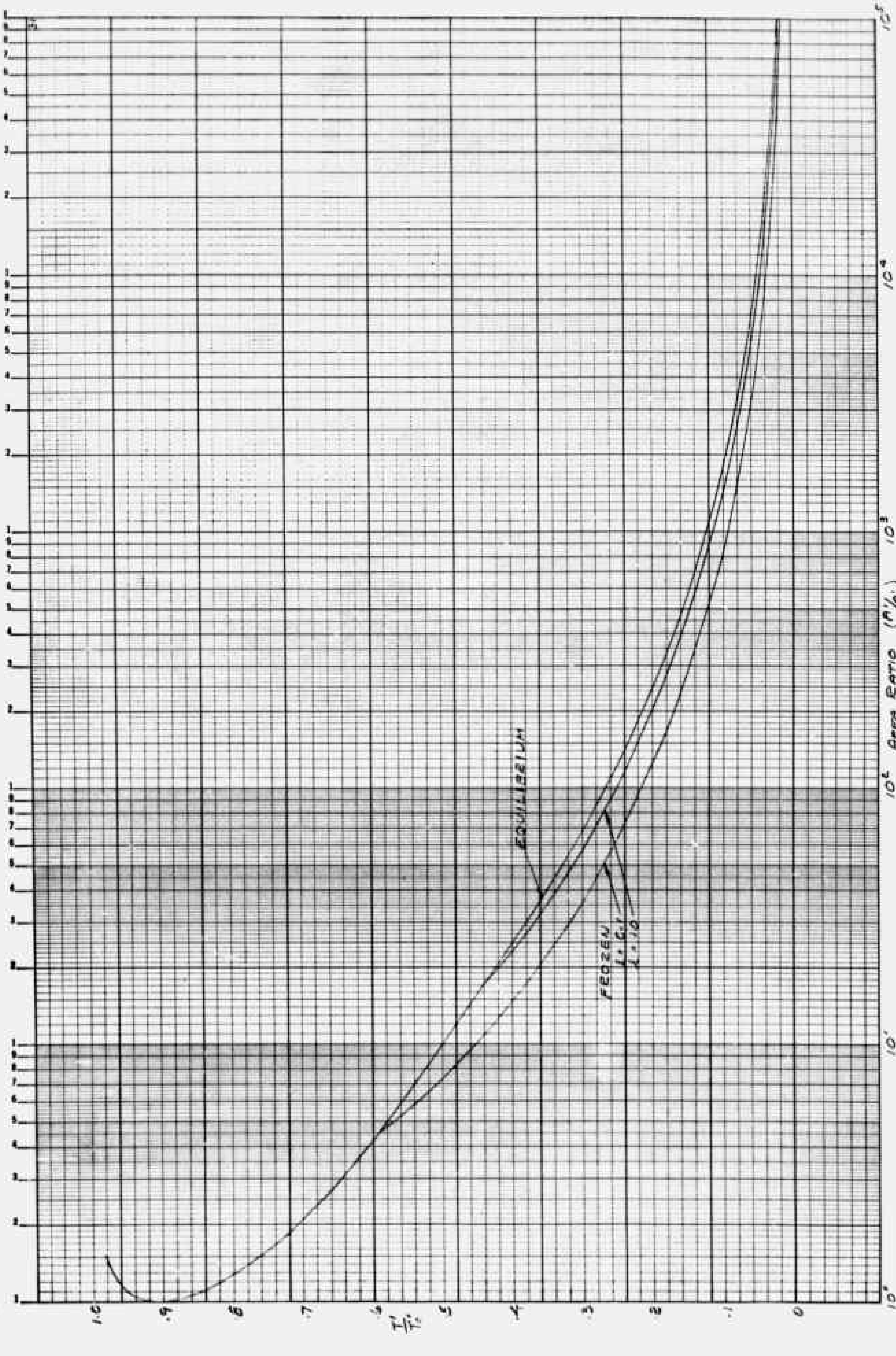

FIGURE NO. 31c HYPERBOLIC NOZZLE $T_c' = 6000\,°K$ $P_o' = 1000$ ATM